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THE STRATIGRAPHICAL POSITION OF THE CHERRA SANDSTONE, ASSAM. BY A. M. N. GHOSH, B.Sc. (LOND.), A.R.C.S., *Geologist, Geological Survey of India.*

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BY A. M. N. GHOSH, B.Sc. (LOND.), A.R.C.S., *Geologist, Geological Survey of India.*

CONTENTS.

I. INTRODUCTION.

Prior to recent geological work in Assam certain coal bearing sandstones occurring beneath known Eocene strata in the Garo and the Khasi hills were regarded as Cretaceous in age. Recent investigations by Dr. C. S. Fox in the Garo hills, however, have led him to conclude that these so called 'Cretaceous' sediments actually form a connected sequence with the overlying Eocene and are, in fact, a part of the basal Tertiary succession. The coal-bearing Cherra sandstones of Mawbehlarkar (25° 24′ : 91° 15′) in the Khasi hills were also previously correlated with the above mentioned 'Cretaceous' sandstones of the more western outcrops in the Garo hills but, on studying the sequence Dr. Fox came to the

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conclusion that the Cherra sandstones also formed a part of the Eocene succession of Assam (Fermor, 1935, p. 82).

Scope of work.

About the beginning of the year 1935, Dr. Fox deputed me to investigate further the stratigraphical position of the Cherra sandstone as developed along the southern side of the Shillong plateau, and initiated me into the geology of the Khasi hills at Therriaghat (25° 11′ : 91° 46′) where, on the east bank of the Um Sohryngkew, the Cretaceous and Eocene beds are best developed. At his suggestion, the Cherra band was separately mapped from the fossiliferous Eocene (Nummulitic) beds above it and the fossiliferous Cretaceous below it.

Area surveyed and maps used.

The area, which is a portion of the Shillong plateau of the Khasi hills, surveyed by me during the field seasons 1935 to 1937, lies between the parallels of latitudes 25° 10′ and 25° 30′ and longitudes 91° 37′ and 92° 00′, and is covered by the one inch sheets 78 0/11, 0/12, 0/15 and 0/16. It is bounded by the Umiew river on its western and by the Um Ngot on its eastern sides respectively.

Previous workers.

Previous workers in the area included T. Oldham, whose observations on the sedimentary beds of the Khasi hills are recorded in the first volume of the memoirs of this department (Oldham, 1858, p. 99, etc.). Oldham introduced H. B. Medlicott to the area and the latter wrote a valuable account of the geology of a strip of the Shillong plateau between Shillong (25° 38′ : 91° 56′), Shella (25° 11′ : 91° 38′) and Therriaghat (Medlicott, 1869, p. 151, etc.). The eastern portion of the area was mapped by P. N. Bose in the early years of the present century. Mention may also be made of T. H. D. La Touche, who studied the coal deposits of Cherrapunji (25° 17′ : 91° 44′), Laitryngew (25° 20′ : 91° 44′) and Mawbehlarkar (La Touche, 1889, p. 169, etc., and 1880, p. 120, etc.).

Nomenclature.

Originally, the term 'Cherra series' was used by Medlicott for the infra-Nummulitic sedimentary beds of the Cherrapunji area. He left the exact horizon of demarcation between Cretaceous and Eocene in doubt but seemed to be in favour of grouping the Cherra band with the nummulitic rocks above it (Medlicott, 1865, pp. 31 and 37). Later he used the name 'Cherra sandstone' for the same beds coming above the fossiliferous Cretaceous and below the Nummulitic limestone of Cherrapunji (Medlicott, 1869, p. 169, etc.). In

the last paper he entered into a lengthy discussion for placing the Cherra band in the Cretaceous but could not produce sufficient evidence to support his views and was not in a position, therefore, to pass any opinion about its age.

In the light of present day knowledge resulting from my own field work in the Khasi hills and the works of Dr. Fox in the Garo hills and Mr. P. N. Mukerjee in the Jaintia hills, the Cretaceous appears to be more limited in distribution and extent than was previously supposed. Most of the beds mapped as Cretaceous in the Garo and the Khasi and Jaintia hills have proved to be the Cherra sandstone, which is now regarded to be Eocene.

Structural features of the Shillong plateau.

The Shillong plateau is an old land surface made of pre-Cambrian metamorphic and igneous rocks. The southern part of the plateau is occupied by basaltic lavas (Sylhet trap), which are capped by the Cretaceous and the Eocene sediments. On the plateau, the sedimentary beds have a gentle southerly dip but below Mahadek (25° 13′ : 91° 45′) and Nongwar (25° 13′ : 91° 39′) they plunge at a steep inclination towards the south. These beds thus form a monoclinal fold, the axis of which runs between E.-W. and E. S. E.-W. N. W. The crest of the fold appears to be faulted. As the area lies in a region of heavy rainfall, denudation has been very active along this zone resulting in steep escarpments, which overlook the swampy plains of Sylhet district from one end to the other.

Dr. Fox considers the structure of the Assam Range to be a warp due to the southerly thrust of the Himalaya and that the southern edge of this warp has become a monoclinal fold in the Khasi hills and an overfold and thrust fault in the Garo hills (Heron, 1937, p. 92).

II. DISTRIBUTION OF THE CRETACEOUS OF THE SHILLONG PLATEAU.

Southern foothills.

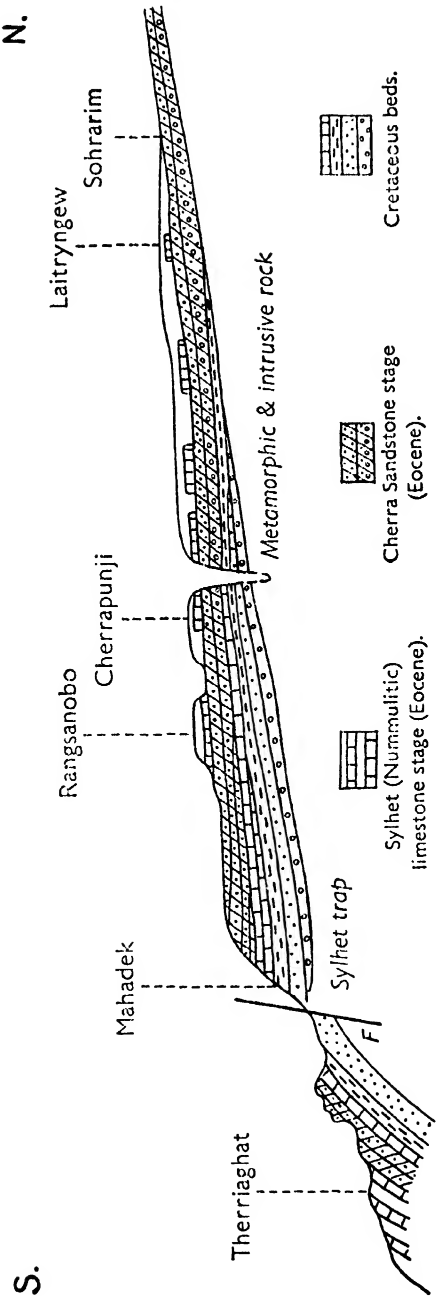
In the submontane tracts on the southern side of the Khasi hills, the Cretaceous formation is represented by arkose and massive, gritty sandstone, the upper part of which is soft, ochreous and earthy and highly fossiliferous and seems to correspond to Medlicott's Mahadek Stage (Medlicott, 1869, p. 178). The stage has a very limited north and south range and cannot be identified everywhere. It is overlain by mudstone, calcareous shale and impure earthy and sandy lime-

stone corresponding to his Langpar Stage (*op. cit.* p. 178). On the east bank of the Um Sohryngkew, the earthy limestone becomes progressively more calcareous and passes upwards into a well-bedded, massive limestone, practically devoid of fossils. Medlicott placed the limestone at the base of his Nummulitic series (*op. cit.* p. 164).

Between Shella and Therriaghat the basal part of the Cretaceous sandstone is either missing or not well exposed for study. Only in one section in the Um Niuh *nala*, E. S. E. of Nongiri (25° 12′ : 91° 48′), the base of the sandstone, near its junction with the underlying Sylhet Trap, was found to consist of fine-grained calcareous sandstone with a few pebbles in it. Between Shella and Turung (25° 11′ : 91° 51′) the sandstone, over a thousand feet thick, is fossiliferous, more particularly near the top, and has a moderate dip of 25°-30° in a southerly direction. The dip steadily lessens in amount east of Turung, and at Dawki (25° 11′ : 92° 01′) it is as much as 15°. The basal sandstone thins out to the north and east and includes bands of conglomerate, of variable thickness, at its base. These are first noticed on the spur east and south-east of Tyrna (25° 14′ : 91° 41′) and on the ridge south of Laitiam (25° 14′ : 91° 45′) and Ryngud (25° 13′ : 91° 46′).

Cherrapunji plateau.

The conglomerate assumes importance further north and in the scarp sections east and E. S. E. of Cherrapunji, is nearly 200 feet thick, where it is overlain, first by massive sandstone (400-500 feet) and then by the band of calcareous shale and earthy limestone (Langpar band), the latter coming below the Cherra band. On the road to Nongpriang (25° 17′ : 91° 45′), north of Cherrapunji, the Cretaceous conglomerate is over 100 feet thick and is overlain by sandstone, shale and sandy Langpar limestone, the latter occurring beneath conglomeratic and pebbly sandstones that form the base of the Cherra stage. In the Cherra gorge, immediately north of the main village of Cherrapunji, the Cretaceous conglomerate is 50 feet thick and in the cliff section, west of ·2405, it is less than 30 feet. The massive Cretaceous sandstone thins out very rapidly from Cherrapunji northwards, finally disappearing south-west of the waterfall ·1023. East of the same falls, about a mile and a quarter south of Laitryngew, the Cretaceous consists of the Langpar band of earthy and sandy limestone with two pebble bands, each 18″ thick, at its base. The conglomerate is well developed on the terrace, south of Laitmawsiang



Generalised diagrammatic section of the Shillong Plateau showing the distribution of the sedimentary beds. Horizontal Scale : ½ inch=1 mile, Vertical Scale : exaggerated.

(25° 18′ : 91° 45′) and can be traced as far as Laitryngew, north of which it is entirely absent. It is overlain, on this eastern side of the Cherrapunji plateau by the Cherra sandstone beginning with a pebble band at its base. It will be apparent that on the eastern side of the Laitryngew-Cherrapunji terrace there is a progressive overlapping of the lower bands of the Cretaceous by the higher ones and a general thinning of the entire succession in a northerly direction. The age of the basal conglomerate, formed in a transgressing sea, is progressively younger as we go northwards.

On the western side of the Cherrapunji plateau, overlooking the valley of the Umiew river, the Cretaceous is represented by about a couple of hundred feet of massive sandstone. The basal conglomerate and the calcareous earthy beds of the upper horizon are absent. The massive sandstone is followed above by two or three pebble bands, each eight to ten feet thick, apparently at the base of the overlying band of the Cherra sandstone. This conglomerate is different from the lower conglomerate so well developed on the eastern side of the plateau and seems to belong to the Cherra stage. The sheer cliff formed by the Cretaceous sandstone thins out further north and disappears under the upper cliff of Cherra sandstone, south-east of ·4430, S. S. W. of Ryngimawsaw (25° 20′ : 91° 41′). Looking westwards along the cliff face below Mawsynram (25° 18′ : 91° 35′) the lower sandstone band of the Cretaceous can be seen thinning in a northerly direction.

South-east Khasi hills.

Along the south-eastern side of the Khasi hills, the Cretaceous beds are not so well developed and the upper beds are frequently denuded away. The massive sandstone shows gradual thinning in the Um Krem, the Um Lyngdoi and the Um Jashar valleys. The sandstone with a pebble band at its base in the valley of the Piyan Gang near Dawki is considerably reduced in thickness. Between Dawki and Mawshun (25° 14′ : 91° 58′) the sandstone thins rapidly. The basal conglomerate, at first, is associated with massive sandstone supporting the calcareous beds of the upper band but in a northerly direction the sandstone passes into sandy and earthy limestones carrying echinoids and *Ostrea*. Pebbly sandstones and conglomerate, less than 50 feet in thickness, are exposed along the motor road between Phlangpontung (25° 15′ : 91° 57′) and Phlangudiak (25° 17′ : 91° 55′), where they are succeeded by ash coloured earthy and sandy limestone of the upper band. In the river beds east and north-

east of Mawlyndun (25° 16′ : 91° 54′), the conglomerate is associated with the same earthy beds.

Outliers of the Cretaceous conglomerate, from which the overburden of the sandy limestone has been entirely removed by denudation, occur in the neighbourhood of the villages of Pynter (25° 16′ : 91° 58′) and Mawpran (25° 18′ : 91° 57′), and continue beyond the E.-W. *nala*, immediately north of Wahtyrsaw (25° 18′ : 91° 55′). In the bed of the *nala*, the conglomerate is over six feet thick and is overlain by Cherra sandstone. Pebble bands in soft sandy beds are present, near their junction with metamorphic rocks, on the footpaths descending to Myllad (25° 19′ : 91° 56′) and Mynrieng (25° 19′ : 91° 53′), E. N. E. and north-west respectively of Pynursla (25° 18′ : 91° 54′) but they cannot be identified further north. It seems that the true Cretaceous beds do not extend north of Khyrwet (25° 19′ : 91° 54′) where, in the cliff section west of the village, the conglomerate, so well developed in the stream beds and on the motor road E. S. E. and south-east of Pynursla, is represented by a few scattered pebbles.

It will now be apparent that the Langpar band of calcareous shale and earthy and sandy limestone is more consistent and widespread than the lower sandstone and it progressively overlaps the latter shorewards in a northerly direction. On the Cherrapunji and the Thang Jnat plateaux it is possible to fix the northern boundary of the Cretaceous within a mile south of the parallel of latitude 25° 20′. It is about this latitude that the calcareous earthy beds of the Cretaceous disappear. It may be observed in passing that R. W. Palmer noticed a break, within the Cretaceous rocks of the western Khasi hills, roughly along the parallel of latitude 25° 22′ (Palmer, 1924, p. 158). It is difficult to say whether the Cretaceous sea transgressed this line from the southern side or not, but evidence in favour of any such possible transgression within the Cretaceous period is wanting.

III. GENERAL FEATURES AND DISTRIBUTION OF THE CHERRA SANDSTONE.

Lithology of the Cherra sandstone.

Before dealing with the distribution of the Cherra sandstone, which overlies the fossiliferous Cretaceous and occurs below the Eocene Nummulitic (Sylhet) limestone, a short description of its lithological and other features may be given. The Cherra sandstone is

essentially a shallow water marine deposit (Heron, 1939, p. 59). There is a possibility that the clay bands it contains may have been deposited under fluviatile and lacustrine conditions. False-bedding of the sandstone is very common. This suggests that the sandstone was subjected to strong current action while it was being deposited. There is no constancy either of the texture, composition or colour of the sandstones which vary from place to place. The sandstone is *fine*—to coarse-grained in texture and is sometimes very hard and compact and makes good building stone. At many places, however, it is extremely friable and powdery. It is felspathic at places and highly quartzose at others. Between Therriaghat and Mawblang (25° 14′ : 91° 44′) there are evidences of the sandstone having been formed by the leaching out of the calcium carbonate of a sandy limestone and secondary quartz has been noticed in the sandstone formed as a result of the replacement of the lime of the sandy limestone by silica. The sandstone is frequently pitted, very likely due to the falling out of nodules of pyrites, which have been noticed at many places. Efflorescence of sulphur is quite common. As a rule the sandstone is light cream and buff coloured but it also presents a variety of other colours and carries bands of variegated sandy shale and lumpy mottled clay. Sometimes the sandstone carries bands of carbonaceous shale and at places it is definitely carbonaceous. In the Mawsmai Falls, a thin band of coal was noticed in the sandstone and at Mawbehlarkar the Cherra band carries a workable seam of coal. Indistinct plant remains are noticed at places in the sandstone otherwise it is practically devoid of fossils, which have only recently been found at one place in the Khasi hills (Heron, 1939, p. 60).

Cherra stage of Therriaghat.

At the foot of the Cherrapunji plateau, in the neighbourhood of Therriaghat, the Cherra stage is represented by massive limestone passing upwards through a sandy limestone into a fine grained, yellowish sandstone showing ill-preserved plant remains in all some 400 feet thick. On the east bank of the Um Sohryngkew, the lower part of the limestone is earthy and grades downwards into the impure, earthy limestone and calcareous shale (Langpar band) of the Cretaceous. Medlicott placed the massive limestone band at the base of his Nummulitic series and its position above the Langpar band agrees with this classification (Medlicott, 1869, p. 164). The overlying band of the plant bearing sandstone is succeeded by

the foraminiferal limestone belonging to the lowest band of the Sylhet limestone (Heron, 1936, p. 85).

Although the Cherra stage is present on the hills south and E. S. E. of Nongiri, it is not well represented in the area between Therriaghat and Shella, where the country is very broken. The partial absence of the beds of the stage may be in part due to local slips and to the underground solution and removal of the limestones and sandstones and thus causing the upper beds to sag and collapse. On the terrace, west of Mahadek, the Cherra beds have been removed by denudation but they are present as outliers on the ridges on which are situated the villages of Nongwar and Laitkynsew (25° 13′ : 91° 40′).

Cherra beds of the Cherrapunji plateau.

The Cherra band is best developed on the Cherrapunji plateau, where the succession consists of 300-400 feet of sandstones with interbedded shales. The sandstones are almost horizontal and when inclined have a very gentle dip towards the south. They can be traced as a continuous band for about ten miles in a north-south direction between Mawblang on the south and Lad Mawphlang (25° 22′ : 91° 45′) on the north. South-east of Cherrapunji as well as in the Mawsmai Falls, the beds are pebbly at certain horizons, more especially in the lower part of the stage, which rests on the earthy and sandy limestone belonging to the Langpar band of the Cretaceous. At the cliff section at Rangsanobo (25° 15′ : 91° 44′), south of Cherrapunji, the Cherra sandstone is conformably overlain by Nummulitic limestone, no sign of any physical break being visible between the two sets of beds.

Infra-Nummulitic sandy limestone, similar to the Cherra limestone at Therriaghat, was noticed in a stream section, west of the path from Mahadek to Mawsmai (25° 14′ : 91° 44′). Here also the calcareous earthy beds of the Cretaceous pass upwards into an impure, earthy limestone with subordinate dark grey, carbonaceous shales and bands of a bluish limestone. Higher up the band the limestone becomes sandy and grades into a calcareous sandstone first and then into a pure sandstone as at Therriaghat. This is the sandstone, which builds up the southern edge of the Cherrapunji plateau. The above-mentioned limestone cannot be traced northwards around the cliff sections of the Cherrapunji plateau, excepting on the descent to Nongstein (25° 17′ : 91° 39′) where an algal lime-

stone, some 200 feet thick, was noticed in corresponding position below the Cherra sandstone about 350 feet from the top of the descent. The limestone rests on a band of sandy clay with a conglomerate about ten feet thick at its base. The succession is underlain by massive Cretaceous sandstone. While the absence of the limestone may possibly be due to a substitution of the calcareous facies of the submontane tracts on the south by an arenaceous facies of the Cherra followed by the Nummulitic (Sylhet) limestone beds on the north, the possibility of the former existence of the Cherra limestone cannot be overlooked, since the presence of large swallow holes in the Cherra sandstone, west and south-west of the motor road at Mawblang, suggests the occurrence of a soluble band as limestone below the sandstone. Similar swallow holes are present in the Cherra sandstone on the southern side of the Thang Jnat plateau near the villages of Wahmawsiang (25° 14′ : 91° 51′), Nongphlang (25° 14′ : 91° 54′) Mawkinber (25° 15′ : 91° 54′) and elsewhere.

Along the footpath descending to Nongriat (25° 15′ : 91° 40′) W. S. W. of Cherrapunji, the Cherra band becomes pebbly and conglomeratic near the base, resting on the sandy Langpar limestone. Similar pebbly and conglomeratic sandstone bands, in corresponding position, are present in the Mawsmai Falls as well as on the eastern side of the Cherrapunji terrace and can be traced along the cliff sections at Falls ·1023 to Laitmawsiang-Mawlyndier (25° 19′ : 91° 46′) terrace resting on Cretaceous beds. The pebble band becomes the basal conglomerate of the Cherra stage, east of Laitryngew, where it rests upon a thin sandy band, possibly belonging to the Cretaceous. East of Sohrarim (25° 21′ : 91° 44′) there are two conglomerates within the Cherra sandstone stage. The upper one appearing some 200 feet from the top of the plateau and is separated from the basal conglomerate, about 150 feet thick, by alternating bands of fine grained and pebbly purplish and cream coloured sandstones. On the western side of the Cherrapunji plateau, the Cherra conglomerate appears much further south, where it occurs at variable depths at the base of the Cherra stage. On the descent to Umblai (25° 17′ : 91° 39′) the pebbles are embedded in a calcareous matrix, which yielded a solitary shark's tooth belonging to the genus *Odontaspis* and a few crushed bivalve shells. The conglomerate on the western side of the plateau increases in thickness in a northerly direction and is well developed on the

terraces overlooking the valleys of the Um Iong, Um Jaut and Umiew rivers, west and north of Sohrarim and more than one such band is present in the sandstone. The conglomerates with their overburden of sandstone rapidly thin out north of Sohrarim, the basal band on the eastern side uniting with its counterpart on the west just north of Lad Mawphlang and the two are met with as one discontinuous band along the Laitsopliah (25° 23′ : 91° 46′) ridge in a barrier of metamorphic conglomerate and quartzite of pre-Cambrian age to Mawbehlarkar, where the Cherra sandstone carries a coal seam and a band of coal shale. A plant impression, similar to that noticed in the plant-bearing sandstone at the Therriaghat section, was found in the carbonaceous shale of Mawbehlarkar. Thin outliers of the sandstone with the underlying conglomerates are present as far north as Steplakrai (25° 25′ : 91° 45′) and also on the hills near Lum Didom, Lum Kyrphai, Umsawmat (25° 24′ : 91° 42′), Lyngiong (25° 25′ : 91° 42′), etc., further north of which the band is very thin and at places consists of loose pebbles, the cover of the sandstone having been eroded away. On the hilltop east of the river Um Sohra, outliers of the Cherra sandstone and conglomerate occur at Mawrap (25° 23′ : 91° 47′) and Mawthawtin (25° 22′ : 91° 46′). The exposure east of Diengsaw (25° 21′ : 91° 46′) includes highly carbonaceous and pyritic sandstone near the base.

Distribution in eastern Khasi hills.

The Cherra sandstone stage is not well developed on the eastern side of the Khasi hills, having been considerably removed by denudation from the southern edge of the Umniuh (25° 12′ : 91° 50′) plateau, only a small patch occurring on the northern side. Between Ringer (25° 14′ : 91° 54′) and Sohlait (25° 11′ : 91° 52′), the sandstone supports dislodged blocks of a sandy limestone, very likely the lowest band of the Sylhet limestone. The Cherra sandstone continues northwards under a thin band of lower Sylhet limestone supporting sandstone with coal at Thang Jnat (25° 17′ : 91° 54′) and Lyngkerdem (25° 21′ : 91° 54′) and ends near Ryngian (25° 22′ : 91° 53′), where it has a thin pebble band at its base. The Cherra sandstone country, south of the Thang Jnat plateau, is very rugged and broken and consists of swallow holes and tumbled masses of the dislodged sandstone.

Outliers of the Cherra sandstone are present at several places further north, the most conspicuous of them occurring south of

Mawlyngngot (25° 24′ : 91° 56′), where the stage is represented by a conglomerate, about 70 feet thick, overlain by a false-bedded sandstone of similar thickness. Here and there on the plateau, east of Laitlyngkot (25° 27′ : 91° 50′) may be found thin skins of pebbly sandstones resting on kaolinised granite and east of Phansawrut (25° 28′ : 91° 53′), an outlier of the sandstone rests on a zone of lithomarge.

Behaviour of the Cherra conglomerate.

It will be noticed that the Cherra conglomerate is extremely variable in thickness and disposition. Although to some extent an uneven land surface may account for its inconsistencies, it is easy to visualise that in early Cherra times the sea bed was oscillating and regression and transgression of the sea was a common feature, resulting in similar phenomena. In the case of marine deposits, when the overlap is of a compound regressive-transgressive nature, the basal conglomerate will rise in the geological scale seawards in the case of the former and shorewards in the case of the latter. This would account for the presence of more than one band of conglomerate in different horizons of the Cherra stage, until more stable marine conditions were finally established.

Northern extension of the Cherra sea.

The Cherra sea must have continued north of the axis of the present Khasi hills plateau, as is indicated by the widespread distribution of isolated outliers of the stage. Such outliers frequently carry thin bands of lithomarge pointing to the condition of weathering in a moist tropical climate that preceded the deposition of these beds. A narrow outlier with a thin conglomerate at its base occurs at Laitdom (25° 36′ : 91° 40′) but, more important, is the faulted outlier at Nongkhrong (25° 37′ : 91° 21′). The latter contains marine fossils of which the forms *Arca*, *Corbula* and *Leda* could be recognised and some imperfect casts of gastropods and a coral (? *Trochocyathus*). The sandstone, in which these fossils occur, is only a few feet thick, and is underlain by gneisses and abuts against laterite on its eastern side (Heron, 1939, p. 59). Dr. Fox considers the beds at the Um Rileng coalfield, seven miles north-west of Shillong to correspond to the Cherra sandstone stage (Heron, 1937, pp. 85-86).

IV. SYLHET LIMESTONE STAGE.

The Cherra sandstone stage is succeeded upwards by the Sylhet (Nummulitic) limestone stage, which consists of limestone, sandstone,

shale and coal. The most complete succession of the stage is on the east bank of the Um Sohryngkew, where it is represented by three highly fossiliferous limestone bands separated by sandstones of variable thicknesses. The uppermost limestone is mostly built of large and medium sized *Nummulite* and *Assilina*. Between Therriaghat and Shella the band is overlain at places by an earthy limestone and marl entirely made of *Discocyclina*. The middle limestone is teeming with *Alveolina*, while the third or basal limestone shows sections of gastropods and tiny foraminifera. The sandstone below the *Alveolina* limestone carries coal south of Maolong (25° 13′ : 91° 42′). On the southern side of the Cherrapunji plateau, the nummulitic beds above the Cherra sandstone have been removed by denudation. In the Rangsanobo cliff, the stage consists of a sandy limestone supporting a sandstone with a coal seam. The limestone,[1] which appears to correspond to the basal band of the Sylhet limestone at Therriaghat, overlies the Cherra sandstone in normal stratigraphical sequence and no sign of any physical break is visible between the two. In comparison with the development at Therriaghat, the limestone is considerably attenuated at Rangsanobo and rapidly thins out northwards. It is present at several places in the scarp sections between Cherrapunji and Laitryngew and is last seen near the villages of Mawkma (25° 20′ : 91° 43′) and Laitlyndop (25° 20′ : 91° 42′). The diminution in the thickness of the limestone northwards is, however, accompanied by a corresponding increase in the thickness of the overburden of sandstone, which in places, when the limestone is absent, passes imperceptibly downwards into the Cherra sandstone. The passage in such cases is so gradual that it is difficult to delineate the boundary between the two stages owing to the lithological similarity of the Cherra and the Nummulitic (Sylhet) sandstones. There is no evidence on the Shillong plateau of the beds of the Sylhet (Nummulitic) limestone stage north of a line joining Lyngkerdem and Sohrarim.

Similarity of Cherra and Nummulitic (Sylhet) sandstones.

The difficulty of differentiating the Cherra from the Nummulitic (Sylhet) sandstones on the Cherrapunji plateau was admitted by Medlicott (1869, p. 168). The two sandstones have features in common which at once suggest their being parts of the same group and

[1] It should be noted that the forms *Assilina* and *Alveolina* found in the two upper limestones at Therriaghat have not been recorded anywhere on the Cherrapunji plateau. The Cherrapunji coal occurs in the same stratigraphical horizon as the coal at Maolong.

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different from the fossiliferous Cretaceous sandstone. The sheer, wall-like scarp caused by the massive and rudely bedded Cretaceous sandstone can be easily distinguished from the overlying cliff of Cherra and Nummulitic (Sylhet) sandstones, with their numerous planes of bedding and intercalated shale and clay. The feature thus provided by these sandstones is very characteristic and apparent all along the cliffs overlooking the deep gorges that dissect the plateau. Further, the bands of lumpy, mottled clay and shale present in the Cherra and the Nummulitic (Sylhet) beds are absent from the Cretaceous strata.

V. STRATIGRAPHICAL POSITION AND POSSIBLE AGE OF THE CHERRA SANDSTONE.

It is the common rule to determine the age of any sedimentary deposit by means of the fossils it contains. The Cherra sandstone, however, is singularly lacking in decent fossils. The few organic remains that the stage has yielded are rather disappointing as they are badly preserved and do not admit of proper study. One has, therefore, to look for other evidences collected in the field. In fixing the stratigraphical position of the Cherra stage, the lithological similarity of its sandstone and shale components with those of the Nummulitic (Sylhet) stage is a point in favour of regarding the two stages as members of the same group and separating the former from the Cretaceous. It has already been stated that on the Cherrapunji plateau no sign of discordance is noticeable between the Nummulitic (Sylhet) limestone and the Cherra sandstone. From Sohrarim northwards only Cherra beds can be traced and the northern outliers may be regarded to represent the higher beds of the same stage of the southern side. Nowhere in the Khasi hills, has the Nummulitic (Sylhet) limestone been found to overlap the Cherra stage and the recent surveys in the Garo and the Jaintia hills have disclosed the same phenomenon. Wherever the Nummulitic (Sylhet) limestone occurs it is supported on a base of Cherra sandstone, suggesting the intimate association of the two.

Unsatisfactory palaeontological evidence.

Conformable sequence of Cherra and Nummulitic (Sylhet) beds.

In the Khasi hills the Cherra stage has overlapped the Cretaceous in a northerly direction. According to Dr. Fox and Mr. Mukerjee, the overlap has also taken place in the direction of the strike of the beds, west-

Evidence of overlap.

wards in the Garo hills and eastwards in the Jaintia hills, suggesting the overlap to be widespread and regional. That the overlap took place after a period of readjustments of the land and sea at the end of Langpar time, is well illustrated in the cliff sections in the Cherrapunji plateau. This is the feature which Medlicott noticed in the cliff face below the main road south-west of the Mawsmai Falls (*op. cit.*, p. 169) and which he thought to be a local feature due to false-bedding, naming it as 'pseudo-unconformability'. In this section the Cherra sandstone is noticed to overlap, in a northerly direction, a sandy limestone, apparently the highest band of the Langpar stage of the Cretaceous. A similar feature is noticeable about the same horizon in the cliff face looking westwards from Mawmluh (25° 15′ : 91° 42′) and also from Pamduloi (25° 18′ : 91° 41′) towards Mawsynram. The overlap is best illustrated in the cliff sections, east of the motor road between Cherrapunji and Laitryngew. Looking towards the west from the Falls ·1023, one can observe the earthy limestone band of the Langpar stage making an angle of 10°-12° with the overlying band of Cherra sandstone, which is almost horizontal in this cliff. On a clear day the same feature is noticeable on a much larger scale looking from Pynursla towards Cherrapunji.

This unconformable overlap, caused by the eustatic movements of the sea, indicates a definite break in the continuity of deposition in the Khasi hills during the Cretaceous-Eocene interval. It is apparent that, following the deposition of the Langpar stage of the Cretaceous, the sea retreated southwards in that area and a gentle dip was imposed on the emerged Cretaceous sediments. In the early Eocene, the sea again transgressed northwards resulting in the deposition of the littoral Cherra stage and the overlying variable strata of the Nummulitic (Sylhet) sequence. From time to time during the Eocene, deltaic conditions prevailed locally. Drifted vegetation brought from inland became buried in the sand and mud and was ultimately converted to coal, the larger accumulations forming definite seams intercalated in the sandstones of the Cherra and the Sylhet limestone stages.

Evidence of the Cherra conglomerate.

The hiatus and the pause in sedimentation preceding Cherra times are further indicated by the occurrence of several bands of conglomerate near and at the base of the Cherra stage and by the absence of the Langpar band from the western end of the Cherrapunji

plateau, where the massive Cretaceous sandstone is also attenuated. It is not unlikely that the attenuation of the Cretaceous beds may represent a local break in sedimentation in Langpar times which became a general feature of the plateau later on. While the Langpar stage was being deposited on the eastern side of the plateau, an upward tilt of the sea bed on the western side would bring the Cretaceous strata within the reach of the agencies of denudation and so thin them down by erosion.

Passage beds at Therriaghat.

The evidences cited above establish a hiatus between the Cherra stage and the fossiliferous Cretaceous beds on the Cherrapunji plateau. In the submontane tract near Therriaghat, however, there is a passage from the undoubted Cretaceous into the massive limestone, which is homotaxial with the Cherra stage of the plateau. It seems, therefore, that while away in the open sea in the Mahadek-Therriaghat region uninterrupted sedimentation was taking place, the present Khasi hills plateau from Mawsmai northwards formed a land surface after the close of Langpar times and remained so till it was submerged again in Cherra times. It is necessary, therefore, to separate the Cherra stage of the Cherrapunji plateau from the Cretaceous, to regard it as the basal stage of Medlicott's Nummulitic series and to place it in the Eocene.

Discussion on the probable age of the Cherra stage.

Although the Cherra stage can be separated from the Cretaceous in the plateau there is not sufficient palæontological evidence to decide the exact age of the stage. The fossils collected and identified by Mr. Mukerjee from the Cherra sandstone of the Jaintia hills are (bivalves) *Macrocallista virgata* d'Orb., *Cardium brongniarti* d'Arch., *Cyprina* cf. *transversa* d'Arch., *Cardita sp.*, *Meiocardia sp.*, and a gastropod, *Natica sp.* The fossils merely indicate Lower Tertiary age but do not allow of a more precise definition. The association

Evidence of laterite.

of the basal portions of the Cherra stage with laterite and kaolin in various parts of the Garo, Khasi and Jaintia hills is an additional evidence for placing the stage in the base of the Eocene, because laterite is known to occur at many places at the base of the Eocene of North West India. Dr. Fox's suggestions, that there was a main laterite-forming period in Northern India in early Eocene times and that the kaolinisation of the gneisses of the Garo hills occurred about the same time (Heron, 1936, p. 34), appear to agree with the available data in Assam.

Age of the Langpar stage.

The points that deserve special attention in this connection are the ages of the Langpar stage of the Cretaceous and the Sylhet stage of the Eocene, since the Cherra sandstone stage intervenes between the two former sets of beds. The fossils that were examined by Spengler are from the sandy Mahadek beds of the Cretaceous and indicate Upper Senonian age, 'that is the Upper Campanian according to Grossouvre or to the Mæstrichtian according to Haug' (Spengler, 1923, p. 65). The overlying band of calcareous shale and earthy limestone (Langpar stage) have yielded casts of numerous gastropod such as : *Xenophora, Cinula, Strigetella, Apphorais, Cyprea, Turritella,* (bivalve) *Corbula,* (echinoid) *Hemiaster sp.,* (scaphoda) *Dentalium sp.,* (ammonite) *Pachydiscus sp.,* ? *Baculites sp.,* and three nautiloids, of which a fragmentary piece shows a close resemblance to *Hercoglossa danicus,* a typical Danian form, while the other two bear similar affinities to the same. Coming as it does on a higher stratigraphical horizon than the Mahadek band, the Langpar stage can, therefore, be placed in a position corresponding to the Danian. 11U518

Age of the Sylhet limestone stage.

As regards the Sylhet limestone stage, it is possible to fix the age of its upper part only, since the different species of *Nummulite,* which have been identified are restricted to the upper limestone. They belong to the upper Laki or Lower Khirthar of the Eocene (Pascoe, 1925, p. 40). The *Alveolina*-limestone of the middle portion of the stage can conveniently be placed in the Laki, but the age of the lowest band of foraminiferal limestone remains undetermined.

Evidence of faunal break.

It has already been stated that between the lowest band of the Sylhet limestone stage and the Langpar band, the equivalent of the Cherra sandstone is represented, on the east bank of the Um Sohryngkew near Therriaghat, by a plant bearing sandstone underlain by a feebly fossiliferous '*massive*' limestone, which carries thin bands of shale near its base and passes into the underlying impure earthy Langpar limestone. The hiatus at the top of the Cretaceous on the Cherrapunji plateau, is, therefore, represented by a continuous series of deposits in the submontane tracts, east of Therriaghat. Although the latter are apparently conformable on the Langpar band on the one hand and to the overlying Sylhet limestone stage on the other, there is a big faunal break, since none

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of the Cretaceous forms survive in the '*massive*' limestone that intervenes, feebly fossiliferous though it may be. It is reasonable to assume that this limestone must have been laid down at a time characterised by such changes in climatic and physical conditions as were hostile to the survival of the specialised fauna of the Cretaceous sea, resulting either in their migration to places where ecological conditions were favouable or the wholesale extinction of these forms. This may be the reason why the '*massive*' limestone is so sparing in organic remains, although they occur in profusion in the limestone bands of the Laki and Danian above and below it respectively. It is evident that Paleocene time was ushered by a cataclysmal change in Assam which explains the impoverishment of fauna in the lower portions of these beds.

Conclusion.

It, therefore, appears reasonable to conclude that these poorly fossiliferous, '*massive*' limestones of Therriaghat together with the overlying plant-bearing sandstones are of lower Eocene (Ranikot) age, bridging the gap between the fossiliferous upper Cretaceous and the Laki. To the north of Therriaghat on the Khasi hills plateau, this Ranikot phase is represented in part by a time interval—evidenced in places by the unconformity that is found at the base of the Cherra sandstone stage—and later by the strata of the Cherra stage itself.

Parallel conditions appear to have prevailed in north-west India where, in Sind, the break between the Mesozoic and the Tertiary is slight or is absent altogether, whilst further north in the Punjab the time interval separating the Mesozoic and the Paleocene is considerable, and is often marked by a prominent unconformity.

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LIST OF PLATES.

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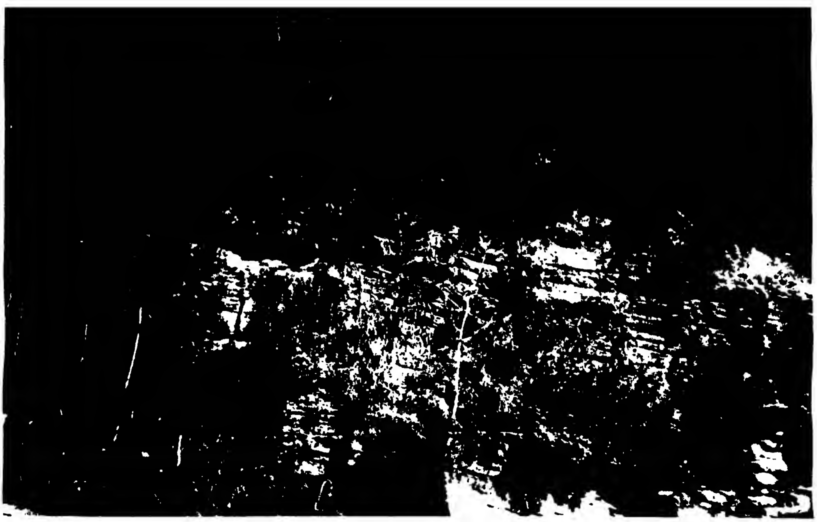
Plate 1.

FIG. 1. CRETACEOUS SANDSTONES DIPPING SOUTH AT 35°.
WEST BANK OF THE UM SOHRYNG KEW.



A. M. N. Ghosh, Photos. *G. S. I. Calcutta.*

FIG. 2. GENTLY DIPPING CRETACEOUS SANDSTONES.
EAST BANK OF THE UM NGOT,
NEAR DOUKI BRIDGE.

Plate 2.

FIG. 1. UNCONFORMITY BETWEEN LANGPAR LIMESTONE (LOWER CLIFF) AND CHERRA AND NUMMULITIC (SYLHET) SANDSTONES (UPPER CLIFF), NEAR FALLS .1023, SOUTH OF LAITRYNGEW.

A. M. N. Ghosh, Photos. *G. S. I. Calcutta.*

FIG. 2. CONGLOMERATIC CHERRA SANDSTONE (WITHIN 200 FEET FROM TOP OF CLIFF), EAST OF CIRCUIT HOUSE, CHERRAPUNJI.

Plate 3.

FIG. 1. CHERRA CONGLOMERATE, EASTERN SIDE OF THE RIDGE, SOUTH OF MAWLYNGNGOT.

A. M. N. Ghosh, Photos.

G. S. I. Calcutta.

FIG. 2. CRETACEOUS CONGLOMERATE, (OVER 500 FEET FROM TOP OF CLIFF), EAST OF CIRCUIT HOUSE, CHERRAPUNJI.

FIG. 3. MASSIVE CRETACEOUS SANDSTONE CLIFF, OVERLAIN BY BEDDED CHERRA SANDSTONE, FOOTPATH TO NONGSTEIN.

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SOME PROBLEMS IN THE GEOLOGY OF THE GONDWANA FORMATIONS.[1] BY M. S. KRISHNAN, M.A., PH.D., D.I.C., F.N.I., *Director, Geological Survey of India.*

CONTENTS

[1] Lecture delivered by the Director, Geological Survey of India, at the Foundation Day of the Fuel Research Institute in November, 1953.

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INTRODUCTION

The earth as a member of the Solar system has been in existence for probably 3,000 million years and the oldest known rocks are about 2,000 million years old. Less than two centuries ago physicists and cosmogonists were of the opinion that our planet was only a few million years old, the utmost they were prepared to concede being not more than 30 million years. This was, of course, a very great improvement and advance on the biblical estimate of 6,000 years only. Geologists, however, have always opined that several hundred million years should be allowed, this opinion being based on a study of the processes of sedimentation going on before us at the present day. The impressive record of sedimentary formations and the evidences furnished by the evolution of fauna and flora indicated a lapse of time which must run into some hundreds of millions of years. Finally, with the discovery of radioactivity, a new tool was available to scientists for the determination of the age of the various strata which contained radioactive minerals, *i.e.*. minerals containing uranium and thorium. The decay of radioactive elements, which proceeds at a constant rate in the case of each element, unaffected by the physical conditions obtaining on the earth, showed that the ultimate products are helium and lead, the latter having different atomic weights depending upon its origin. It is now agreed by Physicists that the age of the earth is of the order of 3,000 million years, though it is rather unlikely that we would find any radioactive mineral yielding any thing like this age. Calculations based upon uranium: lead, thorium: lead and helium ratios, all of which depend upon radioactivity, give us reasonably good data which are acceptable and can be corroborated by other lines of enquiry which are less precise, though indicating the approximate order of magnitude.

A large part of the earth's history belongs to the period when it was too hot to harbour living matter on the surface. This would cover well over 1,500 million years out of the 3,000 million years. It is impossible to find material proofs for the changes which took place on the earth during the earlier part of the period which we call the Archaean or Azoic era. It is only in the Pre-Cambrian, covering a few hundred million years before the beginning of the Cambrian epoch, that the earth

became cool enough to gather water on the surface and to support some form of life. The primitive life which existed in the Pre-Cambrian was all without any hard parts which could be preserved. Even during the Pre-Cambrian era, many and frequent changes occurred, when the surface was invaded by molten material from the interior and the rocks deposited in water or on land were transformed out of recognition into what we call metamorphic rocks.

With the advent of the Cambrian epoch we find an almost sudden appearance of a rich fauna in many parts of the world; but this fauna must have gone through a long period of evolution to have attained such a high stage of development.

There are several relics of revolutionary changes which affected the crust of the earth in the Pre-Cambrian times. These are generally marked by ancient gneissic and granitic rocks associated with zones of mountain building. Five or six such revolutions have been recognised in some of the shield areas of the world, *e.g.*, in Scandinavia, the Baltic region, Scotland, Canada, India, etc. This of course is by no means the full number, but only those which can still be recognised at the present day.

In India we have been able to distinguish at least 4 major periods of diastrophism in Pre-Cambrian times and these may be arranged chronologically as below, together with the ages yielded by radioactive minerals found in pegmatites transversing the rocks of the respective periods.

Dharwarian	2300 million years.
Eastern Ghats	1600 " "
Satpura	950 " "
Delhi	730 " "

Another period of diastrophism the relics of which are found along the Mahanadi valley and in areas adjoining the Eastern Ghats, is also distinguishable, but its relative age has not yet been worked out. The ages given above are those which have been deduced from radioactive measurements by Holmes (1949, 1950).

Since the time of the latest Pre-Cambrian movement which is recognisable as having preceded the Eparchaean unconformity

four major revolutions have been identified. These are referred to as the *Caledonian* (In Ordovician-Silurian times) *Variscan* or *Hercynian* (during the Devonian to Trias) *Mesozoic* or *Cimmerian* (Triassic to Jurassic) and the *Alpine-Himalayan* (Tertiary). Each of these has a fairly long time range and may have taken place in different parts of the world at different periods during that range. The Mesozoic revolution has not been distinguished in India but evidences of it can be seen in the Shan Tableland, Malaya and some other parts of S.E. Asia.

In dealing with the Gondwana formations we are concerned with the period between the Hercynian revolution which took place in the region around India in the Middle to Upper Carboniferous (say, about 225 million years ago), and the Alpine revolution which took place about 60 to 65 million years ago. Alpine revolution lasted from the Upper Cretaceous to the Pleistocene, spanning the whole of the Tertiary era, *i.e.*, a duration of some 60 million years.

The earth's history has therefore been one of a succession of revolutions punctuated by periods of quiescence, the latter affording time for the fauna and flora to evolve gradually from primitive to highly organised and complicated groups.

There is clear evidence that each revolution was accompanied by new mountain-building and by the intrusion of granitic rocks on a stupendous scale. On the Asian continent the different revolutions are seen to spread progressively out from the central mass of Siberia, each succeeding revolution being marked by mountain ranges arranged more or less concentrically farther and farther away from this mass (Umbgrove, 1946). We thus find that the Urals and the mountains of Southern Siberia belong mainly to the Caledonian movements while the Tien-Shan Kun-Lun and Karakorum ranges belong to the Hercynian, and the Nan-Shan and some southeast Asian ranges to the Mesozoic revolutions; and finally the Himalayas and the connected ranges of Mekran and Iran, etc., on the one hand and the Assam-Burma ranges and the Island arc of Indonesia on the other belong to the Alpine-Himalayan revolution.

Each mountain building movement was immediately followed by a period of world-wide glaciation. The earlier glaciations of the Upper Pre-Cambrian and Caledonian have been recognised in a few places but the evidences are not always very clear as

the rocks have often been subjected to metamorphic changes. The evidences of post Hercynian glaciation are quite clear where they have not been disturbed by later movements. Pleistocene glaciation, which is only a few thousand years old, is naturally well recognised everywhere. It covered a large part of North America as far South as Central United States and also a large part of Europe and Asia. The post-Hercynian glaciation, which is recognised in the tillites which lie at the base of the Gondwana formations, and equivalents wherever they are developed, is found in all the lands of the Southern Hemisphere, including India. It is thought that at the time when the Hercynian revolution took place there were two large continental masses, one including all the northern continents excepting India (known as Laurasia), and the other comprising all the lands in the southern hemisphere including India (known as Gondwanaland). Geologists are not agreed whether these two continents were compact masses or consisted of the present units with connecting links which disappeared piece-meal afterwards. However, there is reason to believe, from the extensive distribution of the Gondwana formations in South America, South and East Africa, Antarctica, India and Australia, that they formed one group (as first suggested by W. T. Blanford) to which the great Austrian Geologist Edward Suess later gave the name "Gondwanaland". As will be seen later the Gondwana formations developed in these southern continents have a great deal of similarity in lithology, flora and fauna which several authorities have taken as proving a very close connection between them, despite their wide separation at the present day.

Without more data than are now available, it is difficult to envisage the distribution of land and sea in and around the Indian region just before the Hercynian orogeny. There was a sea in parts of the Himalayan region in the Palaeozoic, for we find sedimentary deposits of that age in Kashmir, Spiti and Kumaon. There is generally a well marked hiatus below the Upper Carboniferous, and this gap often extends down to the Devonian or even earlier periods. In several places the Upper Carboniferous or Permo-Carboniferous rocks are seen to overlap on the Muth quartzites of Devonian age and sometimes even on Silurian deposits, so that, wherever we find a considerable gap we have to infer that the area was not under the sea during the

period represented by the gap. In parts of Kashmir, sedimentation seems to have continued through the Carboniferous and the Permian, but a large part of the sediments is of the nature of pyroclastics or agglomerates with intercalations of beds containing plant and animal fossils as well as volcanic flows. These constitute the 'Agglomeratic Slates' associated with the 'Gangamopteris beds' of Kashmir.

After the period of mountain building, the whole of the Himalayan area, which would include, of course, the regions now forming the Baluchistan and the Burmese mountain arcs, was occupied by a sea which seems to have stretched east-west from Arakan on the east through the Himalayan region, Baluchistan, Iran, Asia Minor and Syria into the Alpine ranges of southern Europe. To this sea or ocean Suess gave the name of *Tethys*. This Mediterranean ocean lasted throughout the Mesozoic era and was gradually dismembered and raised into land during the Tertiary era, the earliest evidence of the Alpine-Himalayan revolution being recognisable as of Upper Cretaceous age, and the latest as of early Pleistocene age.

DISTRIBUTION OF THE GONDWANA SYSTEM

Rocks belonging to the Gondwana system are found only in a few comparatively restricted tracts in India. They are seen in faulted troughs along the Damodar and Son valleys in Bengal, Bihar and Madhya Pradesh, along the Mahanadi and Godavari-Wardha valleys in Madhya Pradesh, Hyderabad and Andhra. The representatives of the lower part of the Gondwana, which include the chief coal-bearing rocks of India, are found as far away as the Salt Range in Western Punjab, in Kashmir, in the Simla Hills and at several points along the sub-Himalayan range as far east as the Abor and Daphla hills in north-east Assam. The representatives of the upper part of the Gondwanas are found in Gujrat on the western side of India and in the Rajmahal hills at the head of the Ganges delta and several places along the eastern coast in Orissa, Andhra and Madras, as well as in north-western Ceylon. A table showing the correlation of the various Gondwana beds recognised in India, is given here. It might however require slight modifications as more precise knowledge becomes available after detailed investigations. The correlation

of the various exposures with each other and with the standard stratigraphic scale is a matter of importance requiring much work.

LOWER GONDWANAS

The lower Gondwanas comprise the Talchir, Damuda (Damodar) and Panchet series, ranging in age from the Upper Carboniferous to the Lower or Middle Trias.

Talchir Series

The basal beds of the Talchir Series are glacial tillites. As mentioned already, the Hercynian mountain building revolution was followed by a period of glaciation of continental dimensions, so that evidences of this glaciation are found scattered over large areas. Glacial beds are seen in many of the Gondwana coalfields of India as well as in the Salt Range where they underlie the Speckled Sandstones. Near Pidh, the Olive Series of the Speckled Sandstone group include the *Conularia* and *Eurydesma* beds of marine origin, referable to the Upper Carboniferous age. These are underlain by boulder beds, the uppermost part of which has yielded spores of plants of the Glossopteris flora. The Conularia beds near Kathwai, also in the Salt Range, have also yielded impressions of *Gangamopteris* and *Glossopteris*, as well as marine bivalves referable to Lower Permian age. It may be of interest to mention here that the spores recently found in the Rhaeopteris beds (Lower Carboniferous) do not contain the simple form winged pollen of the Glossopteris group (*Pityosporites*). It is therefore inferred that the Glossopteris flora had already made its appearance in India during the glacial period in the Upper Carboniferous.

There are some boulder beds, apparently of glacial origin, in the Kashmir-Hazara region (the Tanakki conglomerate overfying of early Glossopteris flora. Intercalations with the plant beds have yielded marine fossils (and some vertebrates) referable to the Upper Carboniferous or Permo-Carboniferous.

There are some boulder beds, apparently of glacial origin, in the Kashmir-Hazara region (the Tanakki conglomerate overlying the Tanawal series) and in the Simla Hills where the Blaini boulder beds are found thrust over the much older Jaunsars and Chails. There are some boulder beds at Bap and Pokaran near the border of Jaisalmer and Bikaner in Rajasthan which

are also thought to represent the Talchir boulder beds, though doubts have been expressed whether both or at least the Pokaran beds might not be of pre-Vindhyan age.

The boulder beds of the Damodar valley contain large quantities of quartzites and gneissic rocks, the former having a great resemblance to the Vindhyan quartzites in the Son valley to the northwest of the coalfields. The Salt Range boulder beds contain materials which appear to indicate that they have been derived from the igneous and metamorphic rocks of Rajasthan and the Aravalli mountains. The boulder beds of the Godavari valley contain rocks some of which are conspicuously exposed in the Eastern Ghats. It is therefore surmised that ice caps of large dimensions occupied the Central Indian and Aravalli areas in the north-west and parts of the Eastern Ghats and the Deccan plateau in the east and south. from which large glaciers flowed out. Detailed work is necessary on the nature and composition of the boulders found in the boulder beds of the different coal-fields, in order to trace definitely their source and to understand the direction of movement of the glaciers which were responsible for their transportation.

The Talchir boulder beds are overlain by a thickness of 500 to 900 ft. of shales and sandstones which comprise the rest of the Talchir series. Both the sandstones and shales have a general greenish or greyish green colour owing to the fact that the iron in them is largely in the ferrous state. The shales are fine-grained and some of them break up into thin slivers, because of which they are called 'needle shales'. They are probably varved clays. The sandstones show much undecomposed felspar. These deposits belong undoubtedly to a cold climatic environment.

Evidences of this glaciation are also seen in the other units of Gondwanaland but the glacial deposits appear at different horizons in the different areas—Lower to Middle Carboniferous in the Tubarao series of Brazil; Middle Carboniferous and Lower Permian in Australia; Upper Carboniferous in South Africa; and so on. The differing ages of the glacial climates in these units are possibly open to the explanation that the South Pole was shifting from one area to another during the Carboniferous and Permian epochs. This may indicate that the pole shifted from the Brazil-Argentine region in Upper Devonian times to

Antarctica in the Middle Carboniferous, to Australia in Upper Carboniferous, to India in Permo-Carboniferous and to South America again in Lower to Middle Permian, as suggested by some recent workers.

Rikba beds

The Uppermost part of the Talchir series, which shows plant fossils in a few places, is known as the Rikba plant beds. The fossils in these are closely allied to those appearing in the immediately succeeding Karharbari beds and are distinguishable from those of the Damuda series which overlie the Karharbari beds. The equivalents of the Rikba beds are found at Karaon in the Deoghar coalfield, Latihar in the Auranga coalfield and near Anukpur and Goraia in the Umaria-Sohagpur coalfield.

Damuda System*

The Damudas comprise the Karharbari, Barakar, Ironstone Shale and Raniganj series. The Karharbari Series (or Stage) is well developed in the Giridih area where it contains some coal seams. This indicates that the climate had already become more favourable for the luxuriant growth of vegetation. The Karharbari Stage consists of grits and sandstones 200 to 400 ft. thick and at least two good coal seams which are being worked. Its equivalents are seen in the Karanpura, Daltonganj, Umaria and few other coalfields and also in the Gangamopteris beds of Khunmu and Nagmarg in Kashmir.

Marine bed near Umaria.—Near Umaria in Rewa, a thin fossiliferous marine bed has been discovered which is of Permo-Carboniferous age and is considered to be equivalent of the Karharbaris or the Rikba plant beds. It overlies the Talchir boulder-bed and passes upwards conformably into the Barakars. The marine fossils include some species of *Productus, Spirifer, Reticularia*, etc., a few crinoid stems and fish remains. They are closely allied to the Permo-Carboniferous marine fossils in the Salt Range, though there is no identity of species. The fossils are dwarfed, probably because the animals were living in an arm of the sea which was rapidly being inundated by fresh water.

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* I have used the term *system* as the Damudas span the entire Permian epoch. Fox has divided the major sub-divisions—Barakar and Raniganj series—into stages so that it would be more appropriate to use the term *system* rather than *series* to designate them.

One other marine exposure has been found in this region recently and it is hoped that further detailed search and exploration in the Narmada valley would reveal the presence of other exposures. It is postulated that the marine connection between this region and the Salt Range was along the Narmada valley through Gujarat, Kutch and western Rajasthan. We know from other evidences that the Narmada valley has been a zone of weakness from the Permo-Carboniferous times almost to the present day, though a large part of the region is covered by the Deccan Traps. Marine connection across Bundelkhand and the Ganges valley to the Tethyan arc, as was postulated by Fox, appears to be untenable because Central Indian region has been dry land, so far as we know, since post-Vindhyan times and does not show any formation younger than the Vindhyans as do the Narmada valley, Gujrat and Kutch. It is therefore clear that the extension of the Umaria marine bed will have to be looked for along the Narmada valley in the region occupied by the Upper Gondwanas, the Deccan Traps and alluvium.

Barakar Series

The Barakar series comprises the most important coal measures of India and is found in practically all the coalfields of the peninsula. It is also found along the foot-hills of the Himalayas where it is thrust over the Siwaliks and is in turn over-ridden by older rocks. In the Himalayan region, however, because of the crushing and thrusting undergone by these rocks, the coal seams are sheared and rendered anthracitic. Recently, new occurrences of Barakars have come to light in the Rangit valley in western Sikkim where A. M. N. Ghosh (1953) has recorded some coal seams which may be workable. Their equivalent to the north of Mt. Everest is the Lachi series which overlies the Mt. Everest limestone and contain boulder beds and marine strata with Permian fossils. Though coal bearing beds occur thrust over the Siwaliks in Eastern Himalayas of Bhutan, Aka Hills, etc., and are regarded as of Gondwana age we are not entirely without doubt whether some of the occurrences may not be of Eocene age as in Upper Assam.

The Barakars attain a maximum thickness of 2,500 ft. in the eastern coalfields, but it is not known whether this maximum is exceeded elsewhere. They consist of sandstones followed by

shales and coal seams, the cycle of sedimentation being repeated many times. The sandstones contain much undecomposed felspar, indicating that oxidation was not very active even during this period. The coal seams as well as the other strata generally thicken in a westerly direction in each of the eastern coalfields. The coal seams in each field are also generally more numerous and less pure in the west than in the east. From this it is inferred that the direction from which the sediments were derived was somewhere in the west, north-west or south-west. This applies to the more eastern coalfields of the Damodar valley for, in the case of the fields lying further to the west in Vindhya Pradesh and Madhya Pradesh, it would appear that the drainage was in westerly direction as is to be expected from the fact that there was an arm of the sea along the Narmada valley. The drainage in eastern coalfields may probably have found an outlet to the east and north-east as several small coalfields are found in Bengal and Santhal Parganas in the direction of the Rajmahal hills. The northern limit of land must have been somewhere in the sub-Himalayan region where Barakar outcrops are known from the Kosi gorge in Nepal, Darjeeling district, Bhutan, etc.

Middle Damudas

The middle division of the Damuda System is the Ironstone Shales of the Raniganj field. The same division has been termed the *Barren Measures* by Fox as it does not contain any workable seams. It does, however, contain streaks of carbonaceous matter and very thin lenticles of coal. It attains a thickness of about 1,200 ft. in the Raniganj field and about 2,000 ft. in Jharia. It becomes thinner in the Karanpura fields and further west. It should however be pointed out that, unless there are indications to the contrary, the Barren Measures would generally be underlain by the Barakars which should be explored for coal. In the Raniganj field this division contains numerous bands of sideritic ore which, near the surface, has generally been converted into limonite. This limonitic ore was used for smelting in the blast furnaces at Kulti until 1912 when the richer ores of Singhbhum became available for smelting.

Raniganj Series

The upper division of the Damudas, namely the Raniganj series is also coal bearing. It attains a maximum thickness of

3,400 ft. in the Raniganj field. It steadily diminishes in thickness towards the west, being only about 1,850 ft. in Jharia and 1,300 to 1,800 ft. in the Karanpura field. It is rich in coal seams in the Raniganj field, less rich in the Jharia field and shows only a few poor seams in the Karanpura field. West of the Karanpura field, this stage becomes thin and does not contain any coal.

Cyclic sedimentation.—In both the Barakar and Raniganj coal measures we get much the same succession of strata repeated over and over again—sandstone, shale and coal. Very often the top of the coal seams is marked by a clear-cut junction with the sandstone which forms the roof. The occurrence of sandstones above the coal seams indicates that there were fairly sharp subsidences of the basin of sedimentation which allowed coarse sediments to be brought in by floods. Whether this process has been helped by repeated faulting of small magnitude is not known. There is little doubt, however, that there has been a series of sharp subsidences of small magnitude throughout the Damuda period.

Drift Origin.—In all the Gondwana coalfields of India, the evidence available points to the fact that the vegetation has been derived from some distance and has been carried and deposited in the bodies of water in these basins, ultimately to form coal. In no case has any upright stem been found in the coal seams, nor roots extending into the underclay. Tree stems are sometimes found, but generally at the top of the coal seams and lying flat. They are mostly silicified except for the cortical portion which has been carbonised. Owing to pressure, the stems are often seen to have been crushed to an elliptical section. It is clear that they represent materials transported for some distance.

It is well known that Gondwana coal is generally high in ash, even the best seams containing 5 to 8 per cent. ash. This applies also to most of the coals of Gondwanaland. The ash is inherent in the coal, being more or less uniformly distributed in the coal substance and therefore difficult to eliminate by washing. These evidences clearly point to the fact that all the coal seams have been formed by drifted vegetation.

Regarding the proportion of coal in the strata I have obtained some data from my colleagues Messrs. D. R. S. Mehta and P. K. Ghosh who have made calculations of the thickness of

certain sections in the eastern coalfields. The proportions of coal to the strata are as follows:—

Jharia Coalfield	*Coal: strata*
Barakar Series	1: 8 to 13
Raniganj Series	1:23
Raniganj Coalfield—	
Barakar Series	1: 8
Raniganj Series	1:35
Karanpura field—	
Barakar Series	1: 8 or 9

In these eastern coalfields the proportion of coal to the strata is quite high, as revealed by the above figures. It is also seen that the Barakars contain some very thick seams, as for instance the Kargali and Bermo seams in the Bokaro coalfield which have thicknesses of 50 to 100 ft. There is also sometimes the coalescence of two, three, or more seams, as in the Chasnala area at the south-east end of the Jharia coalfield, where a seam with a total thickness of about 85 ft. is known.

In his paper discussing the Garo-Rajmahal gap, J. B. Auden (1949) has stated that he considered the small coalfields between Raniganj and the Rajmahal hills as lying along some radiating faults. If this idea is correct, it may be suggested that another important fault runs from the eastern edge of the Raniganj field along the eastern margin of the Rajmahal hills, and continues into the above-mentioned gap. The fault might have originated first in Upper Gondwana or in the immediately post-Gondwana time, but was further accentuated during the Tertiary when the Himalayan movements took place, which were also responsible for the uplift of the Assam plateau.

The coalfields of North Bengal and the adjoining parts of Santhal Parganas indicate a northerly or north-easterly extension of the drainage basin. Where this line of drainage ended is not

clear, because of the fact that there is a wide strip of Ganges alluvium which covers all the older rocks. The presence of coal-bearing Lower Gondwana rocks in parts of the Sub-Himalayas indicates the positions of the swamps and estuaries which existed near the northern margin of the landmass of the time, though these areas must have travelled some distance southwards and thrust in the present position.

Extension under Deccan Traps.—The westernmost exposures of the Lower Gondwanas include the Sonada, Shapur, Patakhera, Mohpani, as well as the Kanhan and Pench valley fields. These are in the neighbourhood of Badnur and Chhindwara. These are separated from the other Gondwana exposures to their south and east by a stretch of the Deccan Traps. Near Nagpur itself is the Kamptee coalfield in which coal was found in some borings some years ago. The trend of the general distribution of the Gondwana rocks of the Godavari valley clearly indicates that they extend into the Chhindwara area. Whether they extend into the area just west and south-west of Bhopal can only be a speculation at present. The neighbourhood of Bhopal, particularly on its east and south-east, is occupied by Vindhyan rocks and it is not unlikely that the Gondwana formations, which occupy a stratigraphic position between the Vindhyans and the Deccan Traps may exist underneath the Traps to the west of Bhopal.

Kamthi Series

The Kamthi beds, which are extensively developed in Madhya Pradesh and also along the Godavari valley, are generally considered to be the equivalents of the Raniganj stage. In the extreme south-east, in the Godavari district, the Kamthis are overlain by plant-bearing beds referable to the Rajmahal Series. The Kamthis differ from the typical Raniganj series rocks of the Damodar valley. In the Chanda district they attain a thickness of about 3,000 ft. but are only 1,000 ft. or less in the Godavari district. They are generally greyish sandstones, often felspathic and coarse, containing only impressions of plants and rarely any carbonaceous matter. They are equated with the Raniganj beds because they contain impressions of fossil plants of that

age. They contain a fair amount of ferruginous materials in patches and occasionally as nodules. They are largely of fresh water origin.

Panchet Series

A fairly definite change of climate took place between the Raniganj and the (later) Panchet times, though this was only the precursor of the dry climate which marked the Middle and Upper Trias. The Panchet strata consist of red clays and coarse sandstones which sometimes become conglomeratic, with a few thin intercalations of limestones. The beds have the characters of those laid down in shallow lakes and flood-plains. There is little or no carbonaceous matter in them. They lie with a slight unconformity on the Raniganj beds. In the Raniganj coalfield they are divisible into a lower and an upper stage, the two together having a total thickness of about 1,400 ft. They contain some remains of labyrinthodonts and fishes and their age is considered to be Permo-Triassic to Lower Triassic.

UPPER GONDWANAS

Mahadeva Series

The Panchets in the Damodar valley are succeeded by the 'Supra-Panchet' beds. These are the equivalents of the Mahadeva series of Madhya Pradesh, which form the Pachmarhi hills. The Pachmarhi sandstones are exposed here between the Bijori beds below and the Denwa beds above. The sandstones are ferruginous and contain thin layers and lenticles of hematite and are entirely devoid of carbonaceous matter. Their age is Middle to Upper Triassic.

In the Son and Godavari valleys they are represented by the Tiki and Maleri beds which have yielded vertebrate fossils indicating Upper Triassic age. The Durgapur beds of the Raniganj coalfield may possibly be their equivalents but they have not yielded any fossils, and may be of Jurassic or even

Miocene age. Some sandstone near Suri, probably related to these, have yielded angiospermous wood of Middle Tertiary age.

Rajmahal Series

The Rajmahal Series, developed in the Rajmahal Hills, consist of some 2,000 ft. of basaltic lava flows with which are intercalated several plant-bearing sedimentary beds whose total thickness is only of the order of 100 ft. These contain a rich fossil flora of Jurassic age. Similar assemblages of plants are found in the Athgarh sandstones of Orissa ; in the Raghavapuram beds in the Godavari district ; in the Vemavaram beds in the Guntur district ; in the Sriperumbudur (Sripermatur) beds in the Trichinopoly district ; in the Sivaganga beds in the Ramnad district ; and in the Tabbowa beds of Ceylon.

The strata in the Godavari and Guntur districts are intercalated with marine sediments which have yielded some ammonites and other fossils. The examination of the ammonites (which are not well preserved) by Dr. L. F. Spath led him to assign an upper Neocomian age to them. The Rajmahal beds which contain the same plant fossil assemblage may be assigned a Middle to Upper Jurassic age. Different authorities have assigned different ages to the Rajmahal beds, from Rhaetic to Lower Cretaceous. Until more precise data become available, especially from marine fossils, it is perhaps best to consider them as representing a part of the Jurassic and especially the upper part. The Kota beds are slightly younger than the Rajmahals (though perhaps partly overlapping) ; the Tabbowa and Andigama beds are more nearly akin to the Kota beds than to the Rajmahals.

Jabalpur Series

The Jabalpur Series, which is well developed near Jubbulpore in Madhya Pradesh is younger than the Rajmahals and of Upper Jurassic to Lower Cretaceous age. They are represented by the Chikiala beds of the Godavari valley and the Tirupati (Tripetty), Pavalur and Satyavedu beds occurring along the east coast.

Umia Series

The Umia Series, which is still younger, is developed in Kutch, isolated from the major Gondwana outcrops. Raj Nath (1933, 1953) has divided this into three stages called Umia, Ukra and Bhuj. They range in age from the Tithonian to the Aptian. The Umia stage comprises barren sandstones, oolitic beds and fossiliferous beds with *Trigonia,* and other marine fossils. The Ukra beds contain some marine fossils referable to the Aptian. The overlying Bhuj beds contain *Zamia*, *Ptilophyllum* and *Palmoxylon,* and their age is therefore Middle Cretaceous (Cenomanian). According to Raj Nath the stratigraphical sequence is:—

Bhuj beds	Beds with *Palmoxylon.* Beds with *Ptilophyllum.* *Zamia* beds.	Middle Cretaceous
Ukra beds	Calcareous shales (with marine fossils).	Aptian
Umia (restricted)	Barren sandstones and shales. Trigonia beds. Barren sandstones. Green oolites and shales. Barren sandstones.	Tithonian
Katrol series		Portlandian and earlier.

IGNEOUS ROCKS

As is well-known, two types of igneous rocks, mica-peridotites and dolerites, are found intrusive into Gondwana formations. The earlier ones are dykes and sills of mica-peridotite (or Lamprophyre) which are very common in the Damodar Valley as well as in the Darjeeling area. They are found to favour weak horizons like faults, coal seams and the lower surface of

sandstones, along which they spread out. All observations go to show that they were very fluid and hot when they were injected. They are rarely found in a fresh condition, even in deep workings, for the alteration is really due to changes brought about by the emanations derived from the magma itself.

The dolerite intrusions generally occur as dykes which often follow straight courses without any reference to local structures and faults, and may probably be related to structures in the basement rocks. They are generally somewhat later in age than the mica-peridotites. They gradually diminish in frequency in the more western fields of the Damodar valley. They are of the same nature as the basalts of the Rajmahal Hills but it is difficult to say whether some of them may not be connected with the Deccan traps.

All the igneous intrusions are later than the Panchet period and presumably of Mahadeva to Rajmahal age. The Rajmahal flows are intercalated with plant-bearing sediments whose age is deduced to be Middle to Upper Jurassic.

FAULTING AND FOLDING

There are generally two sets of faults—one trending W.N.W.-E.S.E. and the other W.S.W.-E.N.E., the first set being generally the more prominent. The strata are also seen to have been folded to some extent, the chief direction of folding being E.N.E.-W.S.W., especially in the fields of the Damodar and Son Valley regions.

The age of the faulting is generally post-Panchet and in some cases post-Mahadeva. In the Godavari valley, the faulting appears to be post-Chikiala. In this region the downthrow due to faulting is greater on the north-eastern side than on the south-western, in contrast with that in the Damodar Valley where the southern side is faulted down more than the northern. In the Raniganj and Jharia coalfields it is estimated that the southern side has been downfaulted to the extent of some 9,000 ft. and 5,000 ft. respectively.

CORRELATION OF INDIAN GONDWANAS WITH THOSE OF OTHER COUNTRIES

The adjoining Figure gives the correlation of the Gondwana systems in the different countries of the former Gondwanaland, *viz.*, South Africa, Australia, Brazil, Argentine and India. It will be noticed that in all cases the basal formations include some boulder beds of glacial origin. In Australia the Kuttung glacial beds are of Lower to Middle Carboniferous age. In South Africa, the glacial beds are generally well-developed in the Upper Carboniferous. In Brazil, glacial deposits occur in Middle Devonian as well as in Middle and Upper Carboniferous ; in some places there are also coal seams in the Upper Carboniferous. In Argentine, glacial beds have been noticed sparsely in Lower and Middle Carboniferous but more markedly in Upper Carboniferous and basal Permian. Upper Carboniferous glaciation is prominent in India and South Africa.

The more important coal seams in all the Gondwana countries appear to be mainly of Permian age, but in Australia and Brazil there are coal seams in the Upper Carboniferous also.

In all the countries of Gondwanaland there is evidence of general desiccation in the Triassic period during which land animals, particularly labyrinthodonts and reptiles, flourished. The lower or Middle Jurassic (and possibly also the Upper Jurassic in some places) was marked by the volcanic flows of basic composition. Thus the Drakensberg eruptives of South Africa are of Rhaetic-Liassic age, while the Serra Geral volcanics of Brazil are lower Jurassic and the eruptives interbedded with the underlying Botucatu sandstones are of Rhaetic age. In Argentine also volcanic rocks appear in about the same horizon.

The general geology of the Gondwana formations has been reviewed in the previous Sections. We shall now consider some of the major problems relating to the Indian Gondwanas which require elucidation by further detailed work.

CLASSIFICATION

There has been a controversy for many years whether the Gondwanas should be divided into two or three major divisions. There are fairly good arguments on both sides. The two-division

CORRELATION OF GONDWANA STRATA.

		S. AFRICA		AUSTRALIA		BRAZIL	ARGENTINA		INDIA
Jurassic		STORMBERG	Drakensberg Volc.		Volcanics etc.		Serra Geral Volc.	Volcanics		Jabalpur Kota Rajmahal Volc.
Up. Trias	Rhaetic	STORMBERG	Cave sst.		Volcanics etc.		Botucatu sst & Volcanics	Gualo-Rio Banco	MAHADEVA	
Up. Trias	Noric	STORMBERG	Up. Molteno Red Beds.	HAWKESBURY	Wianamatta (Up. Ipswich)	SAO BENTO		Ischigualasto-Cacheuta	MAHADEVA	Mahadeva (Pachmarhi)
Up. Trias	Carnic	STORMBERG	Molteno ≡	HAWKESBURY	Wianamatta (Up. Ipswich)	SAO BENTO	Santa Maria Red Beds	Rastros-Potrerillos	MAHADEVA	Mahadeva (Pachmarhi)
Mid. Trias	Ladinic	BEAUFORT		HAWKESBURY	Arenito Hawkesbury (L. Ipswich)	SAO BENTO	Santa Maria Red Beds	Ischichuca-Cerro-de-las-Cabras	MAHADEVA	
Mid. Trias	Anisic	BEAUFORT		HAWKESBURY	Arenito Hawkesbury (L. Ipswich)	SAO BENTO		Ischichuca-Cerro-de-las-Cabras	MAHADEVA	
L. Trias (Scythic)		BEAUFORT	U. Beaufort: Cynognathus, Procolophon; M. Beaufort: Lystrosaurus	HAWKESBURY	Narrabeen; Hunter-Bowen Orogeny	SAO BENTO		Famatina Volcanics	PANCHET	Panchet
Up. Permian		BEAUFORT	Lower Beaufort: Cysticephalus, Endothiodon	KAMILAROI	Newcastle Coal (Dempsey-Tomago) ≡	PASSA DOIS	False Santa Maria	Patquia ××	DAMUDA	Raniganj ≡
M. Permian		BEAUFORT	Lower Beaufort: Dinocephalus	KAMILAROI	Up. Marine ××	PASSA DOIS	Rio-do-Rasto	Patquia ≡	DAMUDA	M. Damuda
L. Permian		ECCA	Ecca ≡; White Band	KAMILAROI	Greta Coal measures ≡	PASSA DOIS	Estrada Nova; Irati Shale	Patquia ×××	DAMUDA	Barakar, Karharbari ≡
Up. Carb.		DWYKA	Dwyka ×××	KAMILAROI	L. Marine (Bacchus Marsh) ×× (Lochinvar) ××	TUBARAO	Tubarao ××× ≡	Patquia ×××; Asturian orogeny	TALCHIR	Talchir ××; Hercynian orogeny
M. Carb.			Lower Shale	KUTTUNG	Up. Kuttung; Kanimblan Orogeny			Up. Tupe, Bajo Vellis		
L. Carb.			Lower Shale	KUTTUNG	L. Kuttung (Burindi)			Tupe ××		
Devonian			Witteberg				Parana			

▨ Hiatus ××× Tillites ≡ Coal

Standard scale.	Gondwana Divisions.	Damodar Valley.	Son-Mahanadi Valleys.	Satpura region.	Godavari Valley.	East coast.
M. Cretaceous	Umia	..	..	..	..	..
L. Cretaceous						
U. Jurassic	Jabalpur	..	Bansa beds	Jabalpur	Chikiala	Tirupati-Pavalur-Satyavedu.
M. Jurassic	Kota	..	..	Chaugan	Kota	Eaghavapuram-Vemavaram-Sriperumbudur.
	Rajmahal	Rajmahal	Athgarh sst.	..	..	Gollapalli-Budavada.
L. Jurassic	..	Dubrajpur	..	..	..	..
Rhaetic	Maleri	..	Tiki	Bagra Denwa	Maleri	..
Keuper	Pachmarhi	Supra Panchet	..	Pachmarhi	..	..
Muschelkalk	..	..	..	..	..	..
Bunter	Panchet	Panchet	..	Almod	Mangli	..
U. Permian	Raniganj	Raniganj	Himgir-Pali	Bijori	Kamthi Chintalpudi	Chintalpudi sst.
M. Permian	Barren Measures.	Barren Measures.	..	Motur.	..	..
L. Permian	Barakar Karharbari.	Barakar Karharbari.	Barakar	Barakar	Barakar	..
V. Carboniferous	Rikba Talchir	Talchir	Talchir	Talchir	Talchir	..
	Tillite	Tillite	Tillite	Tillite	Tillite	..

classification is based mainly on the floral development during the era. The Talchirs, Damudas and Panchets are characterised by Glossopteris flora, but after the dry period of the Triassic a distinctly different flora, characterised by *Ptilophyllum* and *Thinnfeldia* appears and replaces the *Glossopteris* flora entirely. In fact, the *Ptilophyllum* flora of the Jurassic times is of universal character as it is seen to have spread over the whole world, taking the place of the four great floral groups of the Upper Carboniferous and Permian times.

In regard to the three-fold division, the main line of argument relates to major changes in the climate and facies of the formations. The Permo-Carboniferous and Permian are characterised by a humid cold-temperate climate which supported great forests and during which period thick deposits of coal were laid down. This was followed by the dry period of the Triassic when sediments of continental, desertic or lacustrine character were laid down. This epoch does not show the deposition of any coal and the only organic remains seen are bones or impressions of land and amphibious or lake-dwelling animals like reptiles, labyrinthodonts, and fishes. Plant impression are rare. In the Jurassic period, *i.e.*, with the advent of the Rajmahal times, there was again an amelioration of climate which brought about the spread of a new flora, though the coal seams formed during this period are not of economic importance. During this epoch, the earth's crust in Gondwanaland appears to have experienced tension which produced fractures and faults through which much lava was erupted.

Since the most important fossil remains of the whole of the Gondwana era are plants, they have to be given greater importance than the lithological character of sediments connected with climatic vicissitudes. Fox has therefore strongly advocated the two-fold division of the Gondwanas.

Our knowledge of the dry middle period and its deposits in India is still rather scanty. The beds laid down during the Triassic period have to be studied in greater detail so that we can understand the stratigraphy better. It is likely that the period between Upper Permian and Lower Jurassic is not completely represented by sediments of the Panchet, Mahadeva and related formations. There may apparently be stratigraphical

gaps between the Damudas and the Panchets, between the Panchets and the Mahadevas and between the Mahadevas and the Rajmahals. Perhaps the largest of the gaps may be that at the top of the Panchets.

CORRELATION OF FORMATIONS

So far as the Talchir and Damuda series are concerned, the correlation of the beds in various areas is comparatively easy as we have a fair abundance of fossil plants to guide us. But even here, the Raniganj beds do not have the same characters everywhere and are not well developed in the more western areas. Their equivalents in the Central Provinces are the Bijori beds in the Satpura area, the Himgir beds in the Himgir and Raigarh areas, the Kamthi beds near Nagpur and Chintalpudi sandstones in the Godavari valley.

There is a slight unconformity between the Raniganj and Panchet beds in the Raniganj coalfields. The equivalents of the Panchet beds are the Mangli beds in the Godavari valley and (whole or part of) the Almod beds in the Satpura area.

There is apparently a hiatus between the Panchets and Supra-Panchet beds and their equivalents. What its magnitude is in the Central Provinces will be a matter of conjecture until more detailed knowledge is available. The Supra-Panchets are represented in the Satpura area of the Central Provinces by the Pachmarhi-Denwa-Bagra stages (collectively forming the Mahadeva series). The Pachmarhis are apparently represented by the Supra-Panchets of the Raniganj coalfield; the Denwa-Bagra beds are represented by the Maleri (or Marweli) beds in the Godavari valley and the Tiki beds in the Son-Mahanadi valleys.

The Rajmahal series of the type area in Bengal-Bihar is mainly a series of lava flows whose exact age is still a matter of doubt, for they have been assigned to some part of the Geological scale extending from the Rhaetic to the Upper Jurassic. The plant fossils found in the intercalated sediments are not as helpful as marine animal fossils would be for the fixation of age. The plant fossils indicate that their (Rajmahal and Kota stages) equivalents are the Athgarh sandstones in Orissa, the Gollapalle

Raghavapuram stages in the Godavari district, the Budavada-Vemavaram stages in Guntur district, the Sriperumbudur beds near Madras and the Sivaganga beds in Ramnad district. Beds slightly younger than these, and presumably referable to the Jabalpur are the Chikiala beds of the Godavari valley are the Tirupati, Pavalur and Satyavedu beds on the east coast. The Vemavaram, Tirupati and Pavalur beds are associated with some marine intercalations containing species of *Trigonia* and other molluscan fossils. A few ammonites got from these beds (not too well preserved) have been assigned a Neocomian age by Dr. L. F. Spath. We see therefore that the uppermost Gondwana beds of the coast regions extend into the Lower Cretaceous, so that the Rajmahal series may be Upper to Middle Jurassic. It is necessary to collect further data in order to establish particularly the lower limit of the age of the Rajmahal and Kota stages. The finding and precise dating of marine horizons along the eastern coast will also be of help in fixing the age of the coast of the Bay of Bengal.

Though there are no strata immediately following those mentioned above along the eastern coastal region, plant-bearing beds are found associated with marine strata in the Umia series of Kutch. These plant beds overlie marine strata containing Aptian fossils and are therefore of Cenomanian age, at least in part. I am inclined to exclude the Umia group from the Gondwana System because they are isolated from the main Gondwana area and do not directly overlie the Rajmahal and Jabalpur series.

Correlation studies will be greatly helped not only by careful remapping and study of the macrofossils but also by studies of microfossils and spores. Sedimentary petrology is also likely to be of use, at least in limited areas. A little work has been done in the study of heavy mineral suites in the Jharia and Raniganj fields but more data are necessary if they are to be useful in this connection.

SEDIMENTOLOGY

We have at present only rather vague ideas about the source of the sediments which make up the various stages of the Gondwana formations. From the presence of certain quartzite

pebbles, which resemble the Kaimur quartzites in the Son Valley, in the Talchir boulder beds of the Jharia and Raniganj coalfields, Fox deduced that Kaimur quartzite may be the source of these pebbles. With more detailed work and comparison of the heavy minerals present in the sediments with those present in the gneissic and other rocks of the neighbouring regions, it should be possible to deduce the exact sources of the sediments. Such studies would also give us an idea of the direction of movement of the sediments and thus serve to delineate the lines of drainage. From the general distribution of the Gondwana rocks it is now thought that there was one line of drainage to the north-east and east in the eastern part of the Damodar Valley area, and another towards the north-west and west from the Godavari and Mahanadi valleys into the region of the Narmada valley. The presence of Upper Gondwanas near the eastern ends of the Godavari and Mahanadi valleys would indicate a reversal of drainage (*i.e.*, to east and south-east) in the Jurassic. However, detailed studies should now be undertaken for determining the sources of sediments and the directions of drainage as they will help us understand the stratigraphical and structural features.

CORRELATION OF COAL SEAMS

When the detailed mapping of coalfields is conducted, problems of correlation of the coal seams crop up frequently, particularly when seams are cut off by faults and have to be traced on the other side ; similarly also, when seams disappear on tracing them along the strike and others appear further on. For correlation purposes, the physical and chemical studies of the seams, already under way in the programme of the Fuel Research Institute, would be most useful. Studies are also in progress in examining the nature and types of spores in the coal seams which, it is hoped, will be of help in this connection. Sedimentary petrographic studies of the strata intervening between the seams may also lead to useful results. This has not yet been done, but should be worthwhile. The petrographic study of the coals is also a subject which may yield useful results for correlation and other purposes. These various lines of research will naturally take a long time to yield results of practical value. And the greater the volume of data obtained

by careful observations the better will be the chances of drawing useful conclusions from them.

HIDDEN COALFIELDS

As pointed out in a previous section, the coal-bearing rocks of the Godavari Valley are apparently continued into the Badnur and Chhindwara areas, some intervening areas being covered largely by the Deccan traps. There is little doubt that there is a considerable area of Gondwana rocks underneath the traps in this region. All the resources of geology and geophysics should be brought to bear on the problem of delineation of the extent of the hidden strata. At present we cannot say whether seismic wave velocities in the different beds would be sufficiently distinctive and diagnostic to enable us to mark off the coal-bearing strata from others. At any rate, some experimental work should be done on this problem, followed by drilling. If such experimental study in a limited area proves successful, we may proceed with more confidence to investigate other parts of the area where there is a chance of discovery of coal.

MARINE BEDS AND THE STRUCTURE OF THE NARMADA BASIN

Only one thin bed of marine Permo-Carboniferous limestone has been exposed in a railway cutting near Umaria, Vindhya Pradesh; and no attempt has so far been made to locate the continuation of that bed in the neighbouring areas. It is necessary to gather data regarding the extension of this and related formations so as to be able to mark the boundaries of the land and sea of that period. I have held the view that, as the Narmada Valley appears to be a zone of weakness right through from Permo-Carboniferous to Recent times, it is most likely to be the marine zone which connected the Umaria area with Rajasthan and the Salt Range. We are aware that Fox has postulated a marine connection right across the Vindhya mountains and the gneissic tracts of Bundelkhand. As there are no strata younger than the Vindhyans in the whole of that region and there are no other data to support the presence of the sea there since Vindhyan times, there would appear to be little to support that theory.

On the other hand, there is a large patch of Recent alluvium along the course of the Narmada river from Jubbulpore in the east to Harda on the west, and it is bordered to a large extent by the Deccan Traps which are of uppermost Cretaceous to Eocene age. What lies underneath in Narmada-Tapti valleys is not known. It should be interesting to study this area with a view to gaining knowledge about its structure and underground geology.

AGE OF IGNEOUS INTRUSIONS, FOLDING AND FAULTING

Our knowledge of the age of the igneous intrusions into, and of the tectonic disturbances undergone by, the Gondwana strata is still far from precise. Advances can be made in the elucidation of these questions only by extensive field mapping and careful study of structural and other features. Such studies will also provide data for the understanding of the general structure and history of the Gondwana basins. These studies have economic importance in addition to their being interesting from the academic point of view.

Fox has expressed the opinion that the Rajmahal traps were probably the precursors of the Deccan trap activity and that the basic dykes in the eastern coalfields are connected with the Rajmahal traps. We know that the Deccan trap exposures extend as far east as Lohardaga in the Ranchi district, though some of the easternmost outliers are largely, if not entirely, lateritised. If the Deccan traps do extend so far out, it is also reasonable to assume that dykes connected with them would be found in Bihar. In their microscopic and general chemical characters the two groups of basic eruptives appear to be indistinguishable, but the study of trace elements in them may possibly give useful clues for separating them from each other.

There are some of the major problems that await solution. In most cases useful results can be achieved only by the collection of a large amount of data by hard and painstaking work. In this not only will Government Departments and research institutes have their part to play, but also teaching institutions which train students in geological work. It is hoped that these problems will receive attention which they deserve.

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MICROFORAMINIFERA FROM THE *Orbitolina*-BEARING CRETACEOUS ROCKS OF BURMA AND TIBET. BY M. R. SAHNI, M.A. (CANTAB.), D.I.C., PH.D., D.SC. (LOND.), F.N.I., F.P.S., *Palaeontologist, Geological Survey of India* AND V. V. SASTRI, M.SC., F.P.S., *Assistant Geologist,, Geological Survey of India.* (With Plate 2.)

CONTENTS

INTRODUCTION

Recently, while engaged on a monograph* of the orbitolines of the Indian continent, Burma and Tibet, our attention was drawn to the occurrence of a variety of "microforaminifera" in close association with these orbitolines, in fact, within the same thin section. These forms possess two striking characteristics. Firstly, as the name indicates, they are of minute size, attaining

* This is entitled "A monograph of the Orbitolines found in the Indian continent (Chitral, Gilgit, Kashmir) Tibet and Burma, with observations on the Age of the associated Volcanic Series" and is being published as a memoir of the *Palaeontologia Indica.*

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a maximum length of not more than $\frac{1}{2}$ mm. Secondly, they appear to possess the general pattern of certain known genera. However, in our opinion, this similarity cannot be considered as evidence of genetic relationship, for most of the comparable forms are agglutinated types of which there seems no evidence in the genera here reported. Further evidence in support of this view will be found below.

The present record is not the first of its kind for some time ago, Wilson and Hoffmeister (1952) announced the occurrence of similar diminutive foraminifera in Tertiary shales of parts of the U.S.A. and in recent seas, *e.g.*, in the gulf of Mexico and in the deep sea deposits of the Atlantic ocean.

DWARFISM

In recent years, some work has been done on the causes of dwarfism in marine faunas. As this problem is of considerable importance in connection with the present study, and little is known concerning the factors which produce dwarfism, we propose to review briefly the views expressed by various workers in the field. Lalicker (1948) who has investigated the causes and controlling factors of dwarfism among the protozoa, mentions the following as affecting this phenomenon in the group:

"(i) the kind and amount of food, (ii) temperature of the water, (iii) chemical composition and physical conditions of the water, (iv) hydrogen-ion concentration, and (v) light."

It has been observed that these factors inhibit or accelerate growth, according to their relative abundance or the presence, or absence, of certain conditions governing them. Food supply appears to be a very important factor and may result in dwarfs or giants (due to cannibalism) *vide* Dawson, 1919 or even to changes in shape, depending on the nature of the food (Kidder, Lilly and Claff, 1940). 114510

As examples, Lalicker cites *Heterostegina texana* from the Oligocene of Texas in which the size ratio of dwarf individuals to normal ones is 1·5:4·3 mm.; and *Endothyra* from the Mississipian of Illinois where this proportion is ·3 mm. to 1·5 mm. It is reported that in the latter case both normal individuals and dwarfs are present in the same fauna. In the case of the "micro-

foraminifera " under review, all the specimens so far observed are of the dwarfed type, suggesting that food supply was not responsible for their diminutive size. This is further supported by the fact that the remaining fauna is of the normal size.

Preston E. Cloud (1948) offers the suggestion that while retardation of growth may be due to physiological factors, the presence of certain dwarfed faunas may be due to sorting of immature specimens of normally larger forms and adults of smaller species as the result of wave action or moving water. The presence of so-called dwarf faunas may, therefore, be due purely to physical factors. This explanation seems quite plausible. Recently, while engaged in field-work in Nepal, Mr. Muktinath of the Geological Survey of India found shales (Lake deposits) containing opercula of freshwater gastropods which had obviously been sorted out in this fashion. An account of these will be published in due course.

Another very important factor is the pH value of water. According to H. W. Scott (1948), dwarfness takes place when the pH value ranges towards the acidic. This value changes with the depth of water, increasing with it. According to the same author " A pH content of approximately 6·5 will result in retarded activity, a decline in food gathering and food assimilation, and thus result in dwarfing ". This condition is most likely to occur on the floor of tidal lakes, bays, lagoons or land-locked bodies of water where circulation is poor. Benthonic animals such as brachiopods, pelecypods, and gastropods are more likely to suffer dwarfing than free swimming species such as most of the crustaceans. " In the case of the microforaminifera under review, it is obvious that the aforementioned conditions had nothing to do with their minute size, for this fauna flourished in a wide open sea."

According to Moore (1948), the association of dwarfed faunas with oolite, suggests that the same causes which produced the oolites have been responsible for the development of dwarf faunas. He states that " the marginal portions of a retreating shallow sea on the other hand may have had excess salinity because of evaporation in coastal lagoons and drainage of salt from connate waters in the recently exposed salt water sediments left behind the retreating sea margin. If this saltier-than-normal

sea water is an environment in which algae thrive, this may be explanation for some oolites and for the restricted nature of invertebrate assemblages found in some of these deposits."

As there is no association of oolites with the microfauna described in this paper and as there is no evidence of a retreating sea, leaving patches of water with a high degree of salinity, other factors must be looked for to explain the minute size of the forms composing this fauna. Once more we are led to the conclusion that it was not external factors that were responsible for dwarfness of the microforaminifera here reviewed but that this was inherent in their destiny.

We are thus in favour of regarding them as belonging to new genera. These forms are widespread in their occurrence, having been found in thin sections of the Cretaceous rocks of Tibet and Burma. They are, therefore, likely to be of great stratigraphic importance in correlation.

SYSTEMATIC DESCRIPTION

Before giving the detailed systematic descriptions of the new forms here described, a few observations may be made on the nature of their tests as determined by petrographic methods.

The chemical composition of the test of these "microforaminifera" could not be positively determined by petrographical methods, except in the case of the two species of the genus *Kyatsokia* which proved to be calcareous. The tests of the other genera indicated only a small amount of calcite in their composition. Furthermore, we tried to determine the chalk and/or silica content of the tests of these foraminifera after the method detailed by J. Hofker, according to whom "circular polarized light (with a silica plate at 45°) in the polarizing microscope readily reveals the existence of chalk (yellowish on rose background) or of silica (green, purple and blue on rose background) particles in the test material used by foraminifera. It has often been assumed that species of agglutinating foraminifera may choose quite different kinds of particles for building their tests, according to existing circumstances. This view seems to be quite wrong. The study of many species of arenaceous foraminifera, recent and fossil, has revealed to me that each species typically chooses its material as a genetic character of the

species." However, the results obtained by us were not convincing to prove beyond doubt the exact character of the shells. Though such forms among the smaller groups commonly belong to the arenaceous group, the tests of the species under study, do not reveal evidence of agglutination.

An advance notice of the genera and species described below was published in *Current Science* (Sahni and Sastri, 1954).

Genus *Yanbonia*, Sahni and Sastri.

Genotype *Yanbonia moniliforme*, Sahni and Sastri.

(Pl. 2, fig. 1.)

Generic Diagnosis

The only known species is uniserial, chambers bulbous with aperture situated centrally.

Description of Genotype.

Test uniserial, thick-walled, free, elongate, tapering towards the initial chamber. The chambers are subspherical and are arranged in a rectilinear series; sutures straight, at right angles to the axis. The aperture appears to be terminal judging by a change in the contour along the median line of the later formed chambers.

Dimensions.—The only specimen available measures ·5 mm. in length.

Associated species of Orbitolina.—*O. birmanica*, Sahni and *O. raoi**, sp. nov.

Remarks.—A study of the material from several regions, including Chitral, Kashmir, Tibet and Burma shows that the uniserial forms are comparatively rare, for although we have examined several thin sections from rocks of these regions, only a single example from Burma has so far been recorded. The specimen is, however, perfectly preserved and shows all the necessary diagnostic characters. In so far as the nature of the test is concerned, we have been unable to trace evidence of agglutination; therefore the test is probably calcareous, but positive evidence is lacking.

* The species of *Orbitolina* referred to here and subsequently in the same context are those described in the monograph referred to earlier (*vide* footnote, p. 29).

The species bears a general resemblance to certain rectilinear uniserial forms of the Lagenidae, *e.g.*, *Nodosaria*, but no genetic relationship between them is implied.

Stratigraphic horizon.*—Cenomanian.

Holotype.—G.S.I. Type slide No. 17522.

Locality.—Yanbo, Burma.

Genus *Kutaungia,* Sahni and Sastri.

Genotype *Kutaungia cretacea,* Sahni and Sastri.

(Pl. 2, figs. 2-4.)

Generic Diagnosis

Forms initially biserial, becoming uniserial in later stage. The only known species possesses three subdepressed chambers in the uniserial stage.

Description of Genotype

Test biserial in the initial stages, becoming uniserial later; free, elongate, tapering gradually. The biserial stage consists of three to four chambers, with a solitary, more or less circular chamber initially, which might be the proloculum. The uniserial stage consists of three chambers, which number is constant both in the Burmese and Tibetan specimens. The uniserial chambers are flattened and the sutures are more or less at right angles to the median longitudinal axis. The aperture is not visible.

Dimensions.—All the three specimens measure ·2 mm. in length.

Associated species of Orbitolina.—*O. discoidea*, Gras. *O. conoidea,* Gras. *O. birmanica*, Sahni, *O. birmanica*, Sahni var. *kutaungensis,* nov. and *O. raoi*, sp. nov.

* Being new, this species cannot be a reliable index of age, nor are there any forms of known age with which it can be closely compared. We are, therefore, left with the alternative of assigning the same general horizon to it as for the associated orbitolines. The same remarks apply to all the microforaminifera described subsequently, the stratigraphic horizons assigned to them being provisional and inferred from those of the associated orbitolines.

Remarks.—The species under description possesses widespread distribution, for we have found specimens from regions so far apart as Tibet and Northern Burma. The Burma material has yielded two fine examples, while one specimen was obtained from Tibet.

The present species shows general resemblance with species of such genera as *Deckerella* and *Climacammina* and to a slightly less extent with *Bigenerina,* and *Vulvulina* of the family Textulariidae. However, these genera are arenaceous and possess agglutinated tests, whereas the genotype does not show this characteristic.

It may be mentioned here that, in section, only two rows of chambers would be visible and it might be argued that there is the possibility of a triserial, instead of a biserial, stage being present. However, the regularity with which the two series of chambers occur shows that the possibility of a triserial stage is remote.

Stratigraphic horizon.—Aptian-Cenomanian.

Holotype.—G.S.I. Type slide No. 17527.

Paratypes.—G.S.I. Type slides Nos. 16335, 17509.

Locality of Holotype.—Ku Taung, Burma.

Localities of Paratypes.—Yanbo (Slide No. 16335), Burma and (Slide No. 17509) Kyatsok, Tibet.

Genus *Hukawngia,* Sahni and Sastri.

Genotype *Hukawngia problematica,* Sahni and Sastri.

(Pl. 2, figs. 5-6.)

Generic Diagnosis

Forms initially coiled, becoming uniserial in later stage chambers subdepressed ; the uniserial stage consists of four chambers in the only known species.

Description of Genotype

Test free, early chambers planispiraly coiled, later ones uniserial and rectilinear. There appear to be five to six chambers in the coiled portion. The aperture is not observed.

Dimensions.—Of the two specimens, one measures ·2 mm. and the other ·3 mm.

Associated species of Orbitolina.—*O. birmanica* Sahni, var. *Kutaungensis,* nov., *O. raoi,* sp. nov. and *O. hukawngensis,* sp. nov.

Remarks.—This species is confined to the Burmese region and is recorded from the Hukawng valley (Amber mines) and Ku Taung, about 70 miles to the south-west of the Second Defile of the Irrawaddy river.

The species resembles in general pattern certain species of the family Lituolidae, but the differences are striking, the species under report being devoid of agglutinated material which is more or less characteristic of the Lituolidae.

Stratigraphic horizon.—Cenomanian.

Holotype.—G.S.I. Type slide No. 17530.

Paratype.—G.S.I. Type slide No. 17527.

Locality of Holotype.—Amber mines, Hukawng Valley, Burma.

Locality of Paratype.—Ku Taung, Burma.

Genus *Irrawaddia,* Sahni and Sastri.

Genotype *Irrawaddia trigonalis,* Sahni and Sastri.

(Pl. 2, fig. 7.)

Generic Diagnosis

Forms biserial with chambers increasing more or less rapidly in size in later stages producing in some cases (as in the genotype), a sharply triangular outline in section.

Description of Genotype

Test free, elongate, increasing rapidly in later growth stages. The arrangement of the chambers is typically biserial. The sutures are straight in the early stages, becoming more or less incurved obliquely in the later stages of growth.

Dimensions.—The specimen measures ·5 mm. in length.

Associated species of Orbitolina.—*O. birmanica,* Sahni and *O. raoi,* sp. nov. (*vide* footnote p. 437).

Remarks.—In the material examined by us, there is a very characteristic and well preserved specimen of this species from Burma.

The arrangement of chambers in this species suggests a pattern similar to that exhibited by certain genera of the well known family Textulariidae. However, there is no evidence of agglutination in the species under report.

Stratigraphic horizon.—Cenomanian.

Holotype.—G.S.I. Type slide No. 17502.

Locality of Holotype.—Yanbo, Burma.

Irrawaddia tibetica, Sahni and Sastri.

(Pl. 2, figs. 8-10.)

Test free, elongate, tapering. The arrangement of chambers is biserial throughout. The sutures are oblique to the axis. There are 6-7 chambers in each row. The aperture is not observed.

Dimensions.—All the specimens figured are approximately of the same length, *i.e.*, ·25 mm.

Associated species of Orbitolina.—*O. discoidea*, Gras, *O. conoidea*, Gras, *O. concava* (Lmk.), *O. birmanica* Sahni, var. *kutaungensis*, nov. and *O. raoi*, sp. nov.

Remarks.—This species is represented both in Tibet and Burma.

This form bears general resemblance with certain genera of the Textulariidae. A somewhat similar form was figured (camera lucida drawing in outline only) by Fossa Mancini from Shushal, near Leh (Ladakh) and apparently occurs in association with *O. parma* Fossa Mancini and *O. pileus* Fossa Mancini (1928, Pl. XXII, fig. 7).

Stratigraphic horizon.—Aptian-Cenomanian.

Holotype.—G.S.I. Type slide No. 17514.

Paratypes.—G.S.I. Type slides Nos. 17508 and 17527.

Locality of Holotype.—Kham-Sang La, Tibet.

Localities of Paratypes.—Kham-Sang La, Tibet and Ku Taung, Burma.

Genus *Mesania,* Sahni and Sastri.

Genotype *Mesania vermiforme,* Sahni and Sastri.

(Pl. 2, fig. 11.)

Generic Diagnosis

Forms biserial (rectilinear or conical) with chambers of more or less uniform size, except in early stages; sutures concave towards the initial chamber, as a rule.

Description of Genotype

Test free, narrow, elongate, straight, biserial throughout, of uniform width except in the initial stage. The sutures are deeply incurved uniformly wide. The initial portion appears to be slightly conical. Nine to ten chambers constitute each row.

Dimension.—The form measures about ·3 mm. in length.

Associated species of Orbitolina.—*O. wadiai*, sp. nov.

Remarks.—This genus is represented by three species, distributed in Burma and Tibet. The principal diagnostic characteristics of the genus are the large number of chambers arranged in long parallel rows (as seen in two species described below) or in a tapering fashion. The chambers may be subspherical or may show a sharp concavity on the side facing the initial chamber.

The species possesses distinctive characters, and we cannot recall any form with which it might be compared.

Stratigraphic horizon.—Barremian-Aptian.
Holotype.—G.S.I. Type slide No. 17524.
Locality of Holotype.—Mesan, Burma.

Mesania kutaungensis, Sahni and Sastri.

(Pl. 2, figs. 12-14.)

Test narrow, elongate, biserial. The sutures are slightly incurved.

Dimensions.—The maximum length of the form is ·6 mm.

Associated species of Orbitolina.—*O. discoidea,* Gras, *O. conoidea,* Gras, *O concava* (Lmk.), *O. birmanica,* Sahni, *O. birmanica* Sahni, var *kutaungensis,* nov. and *O. raoi,* sp. nov.

Remarks.—It is widely distributed geographically having been found in areas so far removed from each other as Kham-Sang La in Tibet, and Maingtha Chaung and Ku Taung in Burma. This wide geographic distribution which probably extends to other areas is likely to prove of great value in correlation.

The species differs from the previously described species in possessing wider and less incurved sutures.

Stratigraphic Horizon.—Aptian-Cenomanian.

Holotype.—G.S.I. Type slide No. 17527.

Paratypes.—G.S.I. Type slides Nos. 17508, 17519.

Locality of Holotype.—Ku Taung, Burma.

Localities of Paratypes.—Maingtha Chaung, Burma (Slide No. 17519) and Kham-Sang La. Tibet (Slide No. 17508).

Mesania tibetica, Sahni and Sastri.

(Pl. 2, fig. 15.)

Test free, elongate, biserial, gradually tapering. There are eight chambers in each row of the test. The sutures are incurved and tend to widen at their junction with the margin. The general characters exhibited by this form justify its reference to the genus *Mesania*, in spite of its rather tapering form.

Dimensions.—The specimen measures ·4 mm. in length.

***Associated species of Orbitolina.*—*O. discoidea,* Gras, *O. conoidea*,** Gras and *O. obesa*. sp. nov.

Remarks.—This species differs from the other two species of the genus previously described in being slightly conical in shape.

Stratigraphic horizon.—Aptian-Lower Cenomanian.

Holotype.—G.S.I. Type slide No. 17512.

Locality of Holotype.—Kyatsok, Tibet.

Genus *Kyatsokia*, Sahni and Sastri.

Genotype *Kyatsokia tibetica,* Sahni and Sastri.

(Pl. 2, fig. 16.)

Generic Diagnosis

Forms coiled with chambers disposed more or less as in rotalids; test calcareous; number of whorls varying from one and a half to two and a half; chambers increasing very gradually in size.

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Description of Genotype

Test calcareous, free, trochoid, rotaliform, consisting of one and a half whorls. The sutures are oblique to the axis of coiling and are not deeply incurved. Six chambers make up the last formed whorl.

Dimensions.—The maximum length is ·25 mm.

Associated species of Orbitolina.—*O. discoidea*, Gras, *O. conoidea*, Gras and *O. obesa*, sp. nov.

Remarks.—The families Rotaliidae and Anomalinidae containing well known genera like *Rotalia, Anomalina* and *Cibicides*, among the small foraminifera, offer certain comparisons with our form in regard to the disposition of the chambers and mode of coiling. The calcareous nature of the wall of the test in the present species is a conspicuous feature.

Stratigraphic horizon.—Aptian-Cenomanian.

Holotype.—G.S.I. Type slide No. 17510.

Locality of Holotype.—Kyatsok, Tibet.

Kyatsokia multilocularis, Sahni and Sastri.

(Pl. 2, fig. 17.)

Test made up of two and a half whorls, the last formed consisting of nine chambers. This is a more tightly coiled form than *K. tibetica* just described. The sutures are slightly obliquely disposed. A fairly large sized initial chamber appears to be present in the central portion of the test.

Dimensions.—The maximum length is ·2 mm.

Associated species of Orbitolina.—*O. discoidea*, Gras, *O. conoidea*, Gras and *O. obesa*, sp. nov.

Remarks.—This species differs from the one previously described in possessing a greater number of chambers of comparatively small size.

This form is distinguished from *Kyatsokia tibetica* mainly in possessing a larger number of whorls and larger number of chambers of smaller size in the last whorl.

Stratigraphic horizon.—Aptian-Cenomanian.

Holotype.—G.S.I. Type slide No. 17510.

Locality of Holotype.—Kyatsok, Tibet.

ECHINOID SPINES

Besides the foraminifera, a number of thin sections of what appear to be spines of echinoids exhibiting beautiful patterns in cross section have been recorded. However, it is not possible at this stage to refer them to known genera, nor is it proposed to classify them in greater detail. Three different forms are met with and are distinguished as Type A (Pl. 2, fig. 18), Type B (Pl. 2, fig. 19) and Type C (Pl. 2, fig. 20). Types A and B are associated with orbitolines of the *discoidea-conoidea* group and with *Irrawaddia tibetica* (*vide* p. 37). Of these, the former may be compared with the spine of *Aspidodiadema* as figured by Moore, Lalicker and Fisher (1953, p. 710, fig. 5c). Type C occurs with *Orbitolina birmanica* and *Irrawaddia trigonalis* (*vide* p. 36). This may be compared with the spine of *Echinoneus* (op. cit., p. 710, fig. 1). These spines have been figured here as they are likely to be of some value in the correlation of rocks of distant areas.

SUMMARY

(*a*) This paper deals with a new fauna containing foraminifera of minute size.

(*b*) The following types are represented in this fauna which has so far been recorded from Tibet, Ladakh and Burma.

(i) Uniserial (genus *Yanbonia*; *Y. moniliforme*).

(ii) Intially biserial, becoming uniserial in later stages (genus *Kutaungia*; *K. cretacea*).

(iii) Initially coiled, becoming uniserial in later stages (genus *Hukawngia*; *H. problematica*).

(iv) Biserial, with chambers increasing rapidly in size (genus *Irrawaddia*; *I. trigonalis* and *I. tibetica*).

(v) Biserial (rectilinear or conical) with chambers of uniform size throughout except in the early stages. (genus *Mesania*; *M. vermiforme*; *M. kutawngensis* and *M. tibetica*).

(vi) Coiled forms with chambers disposed more or less as in Rotalids (genus *Kyatsokia*; *K tibetica* and *K. multilocularis*).

(*c*) Various conditions conducive towards dwarfism and resulting in known dwarf faunas are discussed. The authors have come to the conclusion that none of these conditions was contributory to the minute size of the forms reviewed here, whose dwarfness is thus a genetic factor.

(*d*) The importance of these foraminifera, which have been overlooked so far, is emphasised in view of their significance in correlation.

(*e*) A few echinoid spines associated with these fossils are figured.

POSTSCRIPT

Since this paper went to the Press, the authors have had an opportunity of examining certain *Orbitolina-bearing* limestones from Dras, Kashmir. It is interesting to record that these Kashmir specimens also contain microforaminifera of the type described from Tibet in the present paper.

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EXPLANATION OF PLATE 2

FIG. 1. *Yanbonia moniliforme*, Sahni and Sastri.—Vertical section showing probable position of aperture indicated by change in outline of bulb-shaped chambers ; × 100, Holotype ; G. S. I. Type slide No. 17522 (p. 33).

FIGS. 2-4. *Kutaungia cretacea*, Sahni and Sastri.—Fig. 2×125; Holotype; G. S. I. Type slide No. 17527 ; fig. 3×120 ; G. S. I. Type slide No. 16335 ; fig. 4×150 ; G. S. I. Type slide No. 17509. Vertical sections showing the three subdepressed chambers of the uniserial portion (p. 34).

FIGS. 5-6. *Hukawngia problematica*, Sahni and Sastri.—Fig. 5×125 ; Holotype ; G. S. I. Type slide No. 17530 ; fig. 6×100 ; G. S. I. Type slide No. 17527. Vertical sections showing the coiled portion consisting of five to six chambers and four somewhat flattened uniserial chambers (p. 35).

FIG. 7. *Irrawaddia trigonalis*, Sahni and Sastri.—Vertical showing rapid increase in size of chambers in later stages ; ×120 ; Holotype ; G. S. I. Type slide No. 17502 (p. 36).

FIGS. 8-10. *Irrawaddia tibetica*, Sahni and Sastri.—Fig. 8×68 ; Holotype ; G. S. I. Type slide No. 17514 ; fig. 9×120 ; G. S. I. Type slide No. 17527 ; fig. 10×120 ; G. S. I. Type slide No. 17508. Vertical sections of three different individuals. Note the gradually tapering test and much smaller size of the shell than in *I. trigonalis* (p. 37).

FIG. 11. *Mesania verniiforme*, Sahni and Sastri.—Note the worm-like appearance of the test in section, and deeply incurved sutures ×124; Holotype ; G. S. I. Type slide No. 17524 (p. 38).

FIGS. 12-14. *Mesania kutaungensis*, Sahni and Sastri.—Fig. 12×45, Holotype; G. S. I. Type slide No. 17527; fig. 13×50; G. S. I. Type slide No. 17508 ; fig. 14×100 ; G. S. I. Type slide No. 17519. Note the vermiform test as in the previous species, but with subspherical chambers (p. 38).

FIG. 15. *Mesania tibetica*, Sahni and Sastri.—Vertical section showing sutures widened at their outer ends×125; Holotype; G. S. I. Type slide No. 17512 (p. 39).

FIG. 16. *Kyatsokia tibetica*, Sahni and Sastri.—Note large coiled chambers *forming 1½ whorls×140 ; Holotype ; G. S. I. Type slide No. 17510* (p. 39).

FIG. 17. Kyatsokia multilocularis, Sahni and Sastri.—Chambers much smaller than in the previous species forming 2½ whorls×105 ; Holotype; G. S. I. Type slide No. 17510 (p. 40).

FIG. 18. Echinoid spine (Type A).—Cross section×27 ; G.S.I. Type slide No. 17514 (p. 41).

FIG. 19. Echinoid spine (Type B).—Cross section×25; G. S. I. Type slide No. 17514 (p. 41).

FIG. 20. Echinoid spine (Type C).—Cross section×40; G.S.I. Type slide No. 17522 (p. 41).

GEOLOGICAL AERIAL RECONNAISSANCE OF THE CENTRAL HIMALAYA ALONG THE KALI GANDAKI (NEPAL), AS FAR AS THE TIBETAN BORDERLAND, ON 18TH OCTOBER, 1949. BY M. R. SAHNI, M.A. (CANTAB.), D.I.C., PH.D., D.SC. (LOND.), F.P.S., F.N.I., *Palaeontologist, Geological Survey of India.* (With Plates 3 to 9.)

CONTENTS

PART I

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PART I

GENERAL

Introduction

The aerial reconnaissance of the Central Himalaya of which an account is given below was carried out on 18th October, 1949. Besides the author, the two other members of the reconnaissance party were my distinguished friends Prof. Arnold Heim of Zurich, whose geological traverses in the trans-Himalaya are well known and Dr. D. N. Wadia, who has earned distinction by his work on the Punjab and Kashmir Himalaya.

The geological and other observations made during this flight are dealt with in Parts I and II of this article. These are supplemented by a series of photographs taken by the writer from the plane, at altitudes varying from 12,000 to 14,000 ft. As a matter of technical interest it may be mentioned that neither a telephoto lens nor filter was used. Fortunately the atmosphere was remarkably clear at the higher altitudes and the oblique light gave unusually fine contrasts. The absence of a filter was, however, not by choice but pure accident, for the only one I carried was gone with the wind at the very first attempt to hold the camera on the frame of the cockpit window for a photograph. The exposure time was 1/200th sec. at f.8, using a 1939 model contax and a Zeiss Ikon 9 × 12 cm camera with a 4·5 lens, the latter purchased while a student at Cambridge in the early twenties.

The main objective of the aerial survey across Nepal as far as the Tibetan borderland, was to elucidate the fundamental structural features of these mighty ranges. It was expected, for example, to determine how far the features already known from traverses in the region further west by Arnold Heim and his colleague, August Gansser, and by geologists and palaeontologists of the Geological Survey of India, among them D. N. Wadia, J. B. Auden, Von Kraft, C. Diener, C. L. Griesbach, F. Stoliczka and others, persisted east and north. Although we

* The publication of this report has unfortunately been delayed for administrative reasons.

saw enough of the area during our 250 mile flight (to and fro over the mountainous region of Nepal) to confirm the main conclusions already arrived at, it would be only right to say that the time at our disposal was insufficient to make detailed observations ; nor was it possible to distinguish individual formations, except broadly. Some of our inferences must, therefore, be treated as tentative and subject to confirmation by ground traverse. The total flight distance from Lucknow to the Tibetan borderland and back was about 600 miles.

This flight was not only the most thrilling experience the writer has ever had, but in spite of several traverses in the higher Himalayas (Buran pass 16,800 ft., Bhairo pass 14,350 ft., Zojila 11,578 ft., etc.), its impress remains unexcelled in scenic grandeur. It would indeed be surprising were it otherwise, for the angle and perspective at which this unending panorama of high mountain ranges and deep ravines, of magnificent dip-slopes, sharp, knife-edge precipices and snow clad peaks, unfolded itself, could never be captured from *terra firma*. As we traversed the valley of the Kali (Krishna) Gandaki beyond its confluence with the Rahughat Khola (28° 8′:83° 35′) the subdued and sombre hues of grey, blue grey, buff-brown and purple of the craggy rocks, with the river hastening like a stream of milk, spilt as it were by the northlying virgin snows, appeared in the softness of the dawn, like a picture torn out of a fairy tale. Ascending higher, and emerging from the valley, the folded mountains forming the Dhaulagiri Himal came to view. Soon we were flying past Dhaulagiri peak itself (Pl. 3), rising almost sheer to a height of 26,795 ft. like a majestic Goddess draped in white, seeming to frown at this noisy intrusion (an R.I.A.F. Dakota), breaking upon her silence and her sanctity. For a long moment, all thought of prosaic rocks and geological structures was forgotten ; everything looked so peaceful, quiet and serene, and blended so beautifully into one harmonions synthesis. Man alone appeared to strike a note of discord in this peaceful setting—geologising amidst the Abode of Gods!

Our mission was completed and we returned, following more or less the same route as on the forward journey, with the light now a little brighter, the changing panorama a little clearer. But the clouds had already begun to rise from the valleys below, soon to envelope the entire landscape.

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DECOMPRESSION CHAMBER TESTS FOR HIGH ALTITUDE FLYING

Mathematics at high altitude.

When we left Delhi our party consisted of thirteen which proved to be a lucky number, for not only did the flight progress according to plan and schedule, but we also had excellent weather and visibility, which enabled us to make observations almost as far as the eye could see. Among the party were, beside the three geologists, five members of the R.I.A.F.—Sqd./Ldr. G. C. Chatterjee (Medical Officer), Flt. Lt. A. Suarez (Captain in charge), Flt. Lt. K. S. Pal (Navigator), P/O. Mitra (Second Pilot), Sgt. Thomas (Radio Officer), together with a Medical Assistant and members of the Ground Staff.

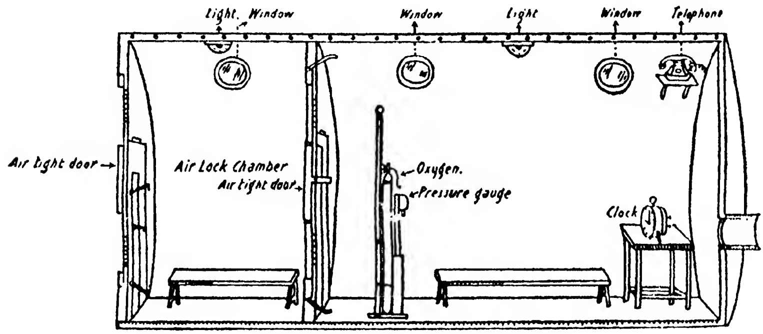

Fig 1. DIAGRAMMATIC VERTICAL SECTION OF *A Decompression Chamber for Testing Suitability of Persons for high altitude flights.*

The Ground Staff having serviced the plane at Lucknow remained behind, so that when the party left for the actual flight we were eight members in all.

Before the flight was undertaken, a certain amount of preparation was necessary. The most important aspect of this, apart from the usual records of heart, blood pressure, pulse rate, etc., was to determine one's physical capacity to fly at high altitudes. This was carried out in the Decompression Chamber.

The Decompression Chamber consists of a horizontal, boiler-shaped, air-tight room, fitted with an oxygen apparatus, gas-masks, telephone, etc., and is fixed to a raised platform (Text-figure I). It is divided into two compartments one of which is smaller than the other, the two being separated by an air-tight door. If a person undergoing the tests shows signs of air-sickness or other acute symptoms upon rarefication of atmosphere, he can be escorted to the adjoining smaller compartment without interfering with the progress of the test. There are a number of port-hole type windows in the Chamber-walls from which the Medical Officer outside keeps constant watch on persons undergoing the test. The physician stationed inside carries out the tests and is ready to administer first-aid, should need arise. As a measure of safety, constant telephonic communication is maintained with the physician outside, who more or less directs operations. It is obvious that even a minor mishap could transform the Decompression Chamber into a death chamber. The main compartment of the Chamber is also provided with a barometer for measuring heights, and a clock to enable one to watch the progress of the 'flight' and rate of 'ascent' or 'descent'. A gauge attached to the oxygen apparatus measures the quantity of gas passing through. This is adjusted with the height, the amount administered varying from 'normal' between 10,000 ft. and 25,000 ft. to 'full' after 25,000 ft.

For the test itself conditions are produced inside the Chamber identical to those obtaining at various altitudes by gradual rarefication of the atmosphere within. No suitable method has, however, been found so far which *progressively* brings abou lowering of temperature at the same time and precisely at the same rate as during an actual ascent. Therefore, at all 'altitudes' (in the Chamber) the temperature remains more or less the same as the atmospheric temperature.

In the case of the present writer, 'ascent' was started at the rate of 2,000 ft. per minute. We 'levelled up' at 5,000 ft., that is, 'ascent' was discontinued for a few minutes for E.N.T. tests. 'Ascent' was continued up to 10,000 ft. at the same rate, when we again 'levelled up' to allow gas masks to be adjusted and oxygen to be switched on. 'Normal' rate of oxygen was allowed up to 25,000 ft. when blood pressure was taken after 'levelling up' and was found to be slightly lower (syst. 124) than prior to

commencement of ascent, namely 130/90. 'Ascent' was continued and 100 per cent. or 'full' oxygen was administered up to 30,000 ft. At this height we 'levelled up' again. While the Chamber was still 'levelled up' at 30,000 ft., oxygen was switched off completely for about 3 minutes and the writer was asked to do a multiplication sum, 4798×182, by the physician inside, in order to test possible change in mental calibre, which takes place at high altitudes. The writer gave the correct answer 873236!. The nails were examined by the physician inside the Chamber. With the rapid loss of oxygen the nails were seen to turn blue equally rapidly, and oxygen was switched on to prevent one becoming further cyanosed, which is a normal reaction at high altitudes. Other effects of the rapid loss of oxygen are that the patient's speech becomes incoherent and he is inclined to give out personal secrets!

The 'return journey' was commenced at 30,000 ft. and 'descent' was carried out at the rate of 2,000 ft. per minute up to 28,000 ft. From this height we 'dived' to 25,000 ft. at a speed of 7,000 ft. per minute. Thereafter, the rate of 'descent' at lower altitudes than 10,000 ft. was slower than at higher altitudes. This procedure is adopted because the *relative* difference in atmospheric pressure is much greater at lower altitudes, and causes stronger reactions, such as sensations in the ear, than at higher altitudes. Precautions are therefore necessary to prevent damage to the ear-drum.

The entire period of the test, that is 'ascent' to 30,000 ft. and back to 'ground level', lasted only about 45 minutes.

Route followed and Details of Flight Timings

Since we were to fly over an unchartered route, the plane carried parachutes as a measure of precaution. We reached Amausi (Lucknow) aerodrome about 4 a.m. At the air-port, Navigator Flt. Lt. K. S. Pal gave us a talk on parachute descent in case of emergency. In the pitch of darkness barely relieved by a frail moon that hung in the dark firmament like a Venetion boat, this talk gave one unaccustomed to such eventualities, an

uncanny feeling for a moment. On entering the plane we were given an actual demonstration of how to don the parachute in case of necessity. Shortly afterwards we were on the move, with the spirit of adventure looming in the far heights!

The route followed, translated along the ground course, is shown in the accompanying map, scale 1″=8 miles (Pl. 9). The more important places falling along the course are Gonda (27° 7′ 30″:81° 58′ 30″), Taulihawa (27° 33′:83° 3′ 30″), Butwal (27° 42′ 20″:83° 27′ 30″), where we enter the mountainous region of Nepal, Tansing (27° 53′:83° 33′). Kusma (28° 14′: 83° 43′), Baglung (28° 16′: 83° 36′) and Mustang (29° 11′: 83° 58′).

After crossing the sharp flexure in its coarse (*see* map), we again entered the valley of the Kali Gandaki about 15 miles north of Tansing. Thereafter we followed the Gandaki valley, mainly due about N.N.E. as far as Dhaulagiri and beyond up to the confines of the Indian borderland *via* Mustang. Beyond Tansing our height varied approximately between 12,000 ft. and 14,000 ft.

The R.I.A.F. (Douglas type) Dakota carrying us took off from Lucknow at 5·8 hours, on the morning of 18th October. The take off could not have been more perfect. Ascending rapidly we attained an altitude of 9,000 ft. in the first 25 minutes. The Medical Officer in charge took the blood pressure at a height of 6,000 ft. and it showed a slight fall over that in the Decompression Chamber.

At 6·1 a.m. the sun broke through the dull grey clouds in the eastern horizon. Albeit, the dark clouds north-eastwards, with a streak of copper, were not too reassuring and Prof. Heim thought for a moment that the prospects were 'not very nice'. Our altitude here was approximately 8,400 ft. We were now flying over Gonda about E. 25° N. and making steadily for Butwal which we crossed at 6·15 a.m. having already entered Nepal territory. The village of Butwal was easily distinguished being situated near the junction of a number of streams fanning out of a single mountain torrent (*see* map). Here we took a more northerly coarse, approximately E. 75° N. and made for the sharp bend of the Kali Gandaki.

It was a most welcome surprise when we saw that the dark clouds which only a few minutes earlier formed a blanket over

the low lying region, had now disappeared, and the entire highland panorama lay stretched before us basking in bright sunshine, except for the shadows in the valleys cast by the greater ranges. The meteorologist had promised us good weather for the morning with 'scattered showers', and we saw the first part of his prophecy fulfilled.

Cruising now at a height of about 14,000 ft. along the magnificent valley of the Kali Gandaki, we maintained steady speed, and by 6·46 a.m. passed the Dhaulagiri peak, 26,795 ft. high, towering above us and appearing, in spite of its distance and our own altitude, like an awe-inspiring phantom in white (Pl. 3 and Pl. 5, figure 2). We followed the valley up to 30 miles or so of Mustang and then struck north.

After touching the remote confines of the northern borderland of the Indian continent, we were again cruising past Dhaulagiri at 7·25 a.m. on our return journey, and landed safely at 8·56 a.m., having circled over Lucknow for about 10 minutes. Our total flight duration was thus a little under four hours, and the total distance covered approximately 600 miles, at an average speed of about 160 m.p.h.

PART II

GEOLOGICAL

General Geological Structure of the Himalaya

The main objective of this flight, as already mentioned, was to determine how far the fundamental structural features of the Himalayas, already known, could be confirmed in the case of the region now traversed.

For an adequate appreciation of Himalayan structures, the geological section from the alluvial plains to the Trans-Himalaya as already determined by Heim and Gansser, and shown in their profile section* of the Central Himalaya, may be explained in broad outline.

The Indo-gangetic alluvium masks the southern edge of the Siwalik sediments consisting of sandstones and clays below and

* *Mem. Soc. Halvetique des Science Naturelle,* Vol. LXXIII, Atlas, Geological map and Section (1939).

conglomerates above (Upper Siwalik), the whole succession attaining a thickness estimated at between 15,000-20,000 ft. The Siwaliks thus occur as a fringe along the outer, convex Himalayan ranges, and themselves form low hills, in general not attaining altitudes over 5,000 feet. Their outer boundary is often an anticline. Over the Siwaliks are thrust a series of calcareous, quartzitic and basic igneous rocks of Krol age. The thrust separating these from the Siwaliks constitutes the Main Boundary thrust dipping north, more familiarly known as the Main Boundary Fault which, incidentally, is responsible for many of the earthquake catastrophies to which Northern India is subject. According to earlier conceptions, this Boundary Fault constitutes the original limit of deposition of the Siwalik sediments, but this idea now needs modification.

The calcareous rocks and quartzites, constituting the Krol zone are followed in the Lower Himalayas by a wide crystalline zone, composed of quartzites, mica schist, granite and gneiss, disposed in a synclinorium of large amplitude. This is followed by another zone of folded calcareous rocks—limestones, dolomite with quartzites and phyllites, showing a lesser degree of metamorphism than the former, and constituting the 'window' limestones, so called because of their having been re-exposed by denudation of overlying cover. North of the 'window series' occurs the Crystalline Central zone of Archaean age, intruded by dykes and forming the "Root" whence the crystalline rocks of the southern area referred to above (as, for example, the region between Ramgarh-Almora and beyond) were shifted many miles southwards.

North of the Crystalline Central zone occurs a series of folded slates, schists and intrusive rocks, which enter into the composition of the higher peaks, such as Nanda Devi. These are flanked immediately northward by the unfossiliferous Garbyang series of presumed Cambrian age. The Cambrian sequence may be said to mark the commencement of the zone designated the Tethys Himalaya, comprising mainly the fossiliferous sequence of Palaeozoic and Mesozoic sediments, the southern region of which presents a series of complicated thrust masses overriding one another. A considerable part of the Himalayan Tethys zone transgresses into Tibet.

North of the Tethys Himalaya lies the much less disturbed region of gently dipping Palaeozoic and Mesozoic rocks often crowded with fossils, and accumulated in a vast, gradually sinking marine basin or geosyncline. These are overlain by a zone of exotic blocks capped by basic lava flows which are in turn covered by Pleistocene gravels. This comprises the Tibetan zone and mainly lies within the Tibetan plateau region.

The rock facies in the Tibetan zone comprising the Kiogars, which include Triassic, Jurassic and possibly Cretaceous rocks with basic igneous rocks (Kiogar facies) and exotic blocks, consisting of Permian, Triassic and Liassic rocks (Chitichun facies) differs markedly from the facies of the Tethys Himalaya. The present position of the former (Kiogars) is due, according to Heim, to a southward thrust from the area some miles south of Kailash.

The Mesozoic limestones underlain by rocks corresponding to the Cambrian Garbyang series reappear north of the Exotic Block zone and seem to be the northward extension of the Tethys Himalaya. Still further north, some miles south of Kailash peak, the exotic block zone seems to be counter-thrust, which has brought these rocks against the horizontal Tertiaries of which Kailash peak is composed. This forms the Trans-himalaya region. The Tertiaries of Kailash peak constitute the highest rocks of that age in the world. In actual fact, the great height at which the conglomerates and sandstones composing the Kailash peak occur, imply a subsidence of the sea floor and its subsequent uplift by over 20,000 feet.

This, in brief, gives an idea of the main geological and structural features of the Himalaya and the Trans Himalaya of the Tibetan region.

The Geological profile between Butwal and Dhaulagiri

The generalised geological profile of the region traversed is shown in Text-figure 2. We cannot but emphasise again that the conclusions drawn herein must be treated as tentative and subject to confirmation by ground observations.

In so far as the region traversed by us is concerned, the sedimentary succession commences near Butwal (27° 42′ 20″ : 83° 27′ 30″) in Nepal territory where we leave behind the alluvial

plain in our northward flight. Although we were flying at a fair height over Butwal, the Siwaliks could be seen dipping steadily northwards. These form comparatively low hill-ranges of almost east-west disposition, and are separated by wide Dun type valleys to the east of the line of flight. One of these ranges is the Mahabharat Lekh which continues for a long distance westward, receding from the plains in that direction. It is possible that the inner Siwalik boundary (Main Boundary Thrust) lies only a few air miles north of Butwal. This is presumed in view of the occurrence northward of peaks rising over 6,000 ft. whereas the Siwaliks normally form lower hills. Flying steadily due almost north, we passed over Tansing (27° 53′: 33° 33′) leaving it slightly to the east. From Tansing our course lay practically N.N.E. and we passed not far from (to the east of) peak 8445, N.N.W. of Lamsaram (28° 2′: 88° 32′ 30″). This peak, and the scarp to its east, appeared suggestive of limestone topography. If this inference is correct, we may have here the equivalent of the window series of Almora, Garhwal and Shali areas (*vide* Auden [1, 2] Heim and Gansser[3], generalised section, and West[4], in chronological order). It would be idle to speculate further in so far as this region is concerned.

This is followed by a wide zone of the well-bedded presumed Dalings consisting of slates and schists, largely pre-Palaeozoic, and intrusive gneiss, which, latter, could be distinguished from the other members by their different hues and colour gradation. While the regional dip is seen to be mainly N. N. E., the Dalings obviously show considerable folding. Though evidence suggestive of marked thrusting did not appear to be clearly visible, the topographic features indicate a thrust contact northward. (Text-fig. 2).

As we proceeded northward, Dhaulagiri, one of the most majestic peaks of the Himalaya came to view—with its arrow shaped crest, deep-cut ridges, separated by sharp ravines. The comparatively high region extending slightly south-west of Dhaulagiri appears to be folded (Pl. 3). This feature appears convincing enough, particularly in view of the clear southward

[1] Auden, J. B., *Rec. Geol. Surv. Ind.*, Vol. 67, pt. 4 (1934).

[2] ———, *Rec. Geol. Surv. Ind.*, Vol. 69, pt. 2 (1935).

[3] *Op. cit.*, Central Himalaya (1939).

[4] West, W. D., *Rec. Geol. Surv. Ind.*, Vol. 74, pt. 1 (1939-40).

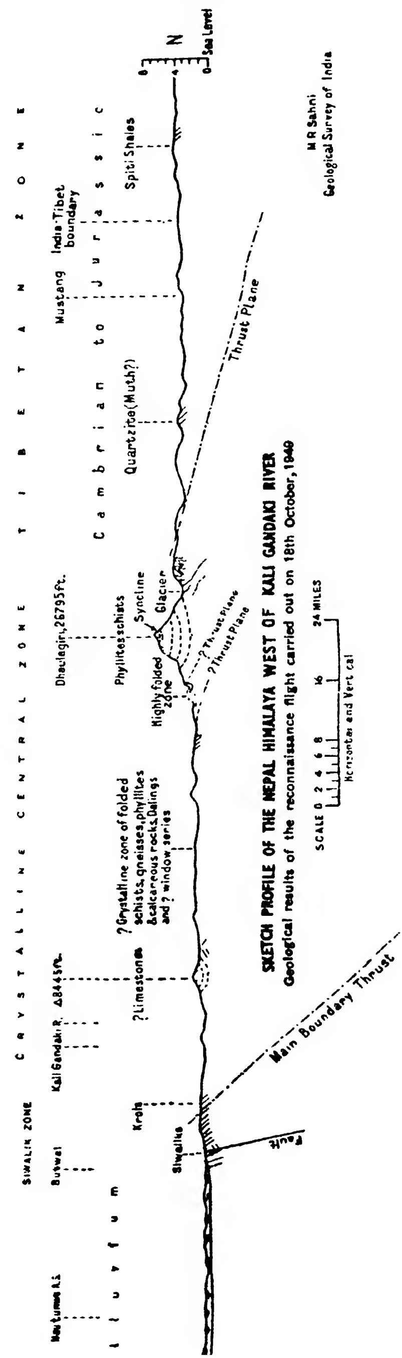
N
Sea Level
0
4
8
TIBETAN ZONE
Cambrian to Jurassic
Spiti Shales
India-Tibet boundary
Mustang
Quartzite (Muth?)
Thrust Plane
M R Sahni
Geological Survey of India
CRYSTALLINE CENTRAL ZONE
Dhaulagiri, 26795 ft.
Phyllites & schists
Syncline
Glacier
Highly folded zone
?Thrust Plane
?Thrust Plane
SKETCH PROFILE OF THE NEPAL HIMALAYA WEST OF KALI GANDAKI RIVER
Geological results of the reconnaissance flight carried out on 18th October, 1949
SCALE 0 2 4 6 8 16 24 MILES
Horizontal and Vertical
?Crystalline zone of folded schists, gneisses, phyllites & calcareous rocks, Dalings and ? window series
?Limestones
Δ8445 ft.
Kali Gandaki R.
Main Boundary Thrust
Krols
Siwaliks
Fault
SIWALIK ZONE
Butwal
Nautanwa R.S.
Alluvium

Fig. 2.

dips seen in the more southerly anticlinal feature. The possibility that the strata possess more or less uninterrupted N. N. E. dips elsewhere should not be entirely overlooked. Indeed, a steady dip of about 30° in that direction is clearly observable in the foreground S. S. E., of Dhaulagiri. This zone might well correspond to the Crystalline Central Zone of the Himalaya (*vide* Heim and Gansser, Atlas and generalised section, already referred to).

The lower and upper contacts of the folded zone appear to be thrust contacts (Pl. 3). The total lack of well defined bedding planes suggests that the folded zone rests upon granite, for, normally, wherever sedimentaries are seen, the bedding planes show up very clearly. As may be noticed from Plate 3, the second anticline from the south is tightly folded and is almost on the point of becoming a recumbent feature. The syncline to the south is asymmetrical while that to the north is more normal, forming probably a thrust contact with the Dhaulagiri massif.

Probable Geological Structure of Dhaulagiri

The foregoing account completes the observations made to the south of Dhaulagiri.

Dhaulagiri itself appears to form a trough-fold of wide amplitude. This feature is noticeable in most of the photographs, and the bedding planes cut across steeply inclined ravines along which denudation has been active, snow and ice gliding unhampered for long distances. Some of these ravines probably follow the direction of joint planes. It is noteworthy that in respect of its synclinal structure (if our interpretation is correct) Dhaulagiri is identical with Nanda Devi, the highest peak of the Central Himalaya, as determined by August Gansser.[1] The rocks composing Nanda Devi are sericitic quartzite phyllite and dolomite quartzite, etc., with dykes of tourmaline aplite. Although we were able to observe basic and granite intrusions in the well-stratified Dalings south of it, in Dhaulagiri itself no intrusions could be seen. This is not surprising for the greater part of this peak is snow-covered, and igneous intrusions would not be visible except to observers on the ground, or if they formed outstanding ledges or other prominent features overshadowing normal topography. As far as can be made out, the folded zone on the south-west flank of

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[1] *Op. cit.*, p. 68 (1939).

Dhaulagiri gives place to what appears to be a thrust, as shown in Pl. 3. One feature that was quite clear is the syncline forming a part of the crest of Dhaulagiri. The folded character is even visible at the southern shoulder of the "arrow" of Dhaulagiri. It is not unlikely that the folded zone forming the Dhaulagiri crest is continuous with the folded zone to the south as seen in Pl. 3. Northward, a wide anticlinorium, now denuded, probably connected up with the southern limb of the north-lying syncline, a part of which is seen in Plates 3 and 4 and the whole in Pl. 6.

Dhaulagiri Hanging Glacier

An imposing feature of Dhaulagiri Himal is the glacier occurring on the eastern flanks of the great peak. It is impressive alike on account of its magnificent setting and dimensions.

As we sped rapidly in the plane, the ever changing perspective was full of surprises but nothing could be more eerie than the sight of this magnificent glacier from a particular angle (facing east) when it appeared like a water-fall pouring into the mists below. It is clearly a hanging glacier, its terminal portion widening out owing to frequent falls of ice (Pl. 5, figure 2).

Another strange sight witnessed in the high ranges further north was a vast, high angled dip slope covered by a sheet of comparatively thin ice which appeared, for a puzzling moment, in the reflected light breaking through the haze, like a lake on an inclined plane, the waters held as it were by some supernatural force!

Evidence of folding north of Dhaulagiri

North of Dhaulagiri, folding appears to be well marked. If our interpretation of photographs is correct, the rocks north of the Dhaulagiri glacier constitute the southern limb of a great synclinal fold with the sharp, snow clad Tukucha peak over 20,000 feet high, rising majestically to the south of the synclinal axis (Pl. 6).

An examination of the photograph (Pl. 4) reveals the following features at the southern end of the synclinal trough: the strata show a tendency to form an overfolded anticline, for the rocks dip first south (from the crest of the ridge lying south of the main peak) and then north, at steep angles. The glacier thus lies in the axial portion of what might be a large recumbent fold probably of the nature of an anticlinorium. The planes of stratification are cut across by what appear to be four major

joint planes, as indicated in the left half of Pl. 6. The interpretation is based on what follows. Further north, almost exactly below the apex of the main peak, the dips become shallower, as is to be expected, and are clearly visible owing to snow lying on the dip slopes. Somewhat higher up, other planes of stratification are seen forming an even bend. The axis of the synclinal trough passes almost exactly through the apex of the first subsidiary ridge, below the main peak. To the north (right) of this ridge, the dips are clearly due south and are seen in and below the next subsidiary northlying peak, proving synclinal structure.

The anticlinal overfold mentioned above is probably connected with the Dhaulagiri syncline. This would imply that the major peaks form synclines while the comparatively lower ground is composed of denuded (overfolded) anticlines. In the foregoing interpretations, however, no infallibility is claimed

Evidence of thrusting

Beyond this, a thrust plane can be clearly seen. I was able to take good photographs of this (*vide* Pl. 5, figure 1 and Pl. 7). The latter shows a bedded succession, apparently dipping at an angle of about 30° due about north-east, overthrust by a highly folded series. The line of thrust appears as a fairly regular zone of small width, gently sloping northward and curving upward in that direction. An important feature that was clearly visible from the plane was a well defined syncline occurring in the folded overthrusts mass (Pl. 5, figure 1). This syncline, the sight of which caused a pleasant stir even among the non-geologists in the plane, is flanked on either side by a tight anticlinal fold of smaller amplitude and dies out northeastward where the folded zone gives place to a normal bedded sequence.

The hill to the north appears to be composed of limestones and shales, of which the former weather into craggy precipices, while the latter give rise to comparatively wide talus slopes. This hill (Pl. 7) is a more or less direct continuation of the feature shown in Pl. 5, figure 1, and exhibits the very gently inclined thrust-plane even more clearly. This is marked by

an almost horizontal line dipping north or northeast about one-fourth the distance below the crest and is seen transgressing the stratification planes dipping at much higher angles, 45° or so.

Further north, the thrust is not visible and probably rises in that direction, truncating a small portion of the adjoining peak above the sharp ridge. This feature probably represents the overthrust of the fossiliferous rocks of the Tibetan zone on to the Crystalline Central zone, though the sedimentary nature (judged from the photograph) of the lower sequence is suggestive of an intra-formational thrust. Reference to the two thrusts south of Dhaulagiri has already been made.

Muth Quartzite

A prominent massive quartzite horizon occurs still further north (Text-figure 2). It was clearly visible from the plane even in the subdued morning light, owing to the sharp contrast with the overlying and underlying formations of comparatively darker hue. Moreover, by virtue of its more resistant character. the quartzite formed a well defined scarp, sloping northward. There seems little doubt that this horizon constitutes the well-known Muth quartzite of Silurian or Devonian age and was so interpreted by my colleague Prof. Heim. It may, however, be noted that no repetition of the quartzite horizon was noticed such as characterises the more western region, where as many as five different thrusts have been distinguished. But of course it was not to be expected that such details wound be made out, even though there was little doubt that we were flying over and along the Tethys Himalaya zone.

The occurrence of Jurassic ammonites in nodules (*saligrams*) has been reported as far south of the Tibetan plateau as Muktinath. If this were confirmed, it would show that the Tibetan zone, in the geological sense, extends fairly far south in this region.

It took us barely 20 minutes to reach the northern Indian borderland after crossing the length (or width) of Dhaulagiri, which we left behind at 6·46 a.m. The barren, tree-less, level waste of the border region, whose monotony is broken here and there by equally barren hills, makes a sharp contrast with the mountain region south of the main Himalayan range, which is often thickly wooded.

In the Indian border region we came down to within about 500 feet of ground level. From this vantage point we could clearly see a solitary, conical peak in the far distant horizon protruding unobstrusively like a little toy pyramid yet rising probably to well over 20,000 feet. In the foreground lay the Matsang Tsangpo or Brahmaputra flowing E.S.E. forming large sheets of water here and there. The Tibetan plateau, a vast almost unbroken expanse, except for low hills (relatively speaking) stretched before us as far as the eye could see bedecked with glacial lakes. Some at least of the dark rocks exposed here are probably basic lava flows though it is impossible to assert this unequivocally.

Region east of Kali Gandaki Valley

In this article we have dealt mainly with the region to the west of the Kali Gandaki. Although the author made a number of observations and took several photograph of important features in the eastern region, the latter (facing east) are mainly in silhouette form, for obvious reasons. Nevertheless those of the Machpuchre-group (so called on account of its resemblance to a fish) and Muktinath, are of interest, but they cannot be reproduced here for lack of space.

Conclusion

It is indeed remarkable how clearly one could at times observe, in spite of the speed of progress and the rapidly changing panorama, the dip of rocks, folds, thrust planes, not to speak of the mountain trails and cirques (Pl. 8). Even photographs taken from *within* the plane, necessitated by having to temporarily close the cock-pit windows owing the biting cold wind were successful. Good visibility helped a great deal and one could see not only the high peaks, but also long stretches of mountains such as the Dhaulagiri Himal south of the Tethys Himalaya and other ranges. On the higher ranges not a speck of cloud was visible. This might almost have contributed to the monotony of the scene, but for its sheer grandeur.

However, in spite of the fact that the stratigraphic and structural features were often clearly seen, one cannot but stress that a considerable measure of speculation must enter into

conclusions drawn from such evidence. Nevertheless, the necessity of such an aerial flight should be emphasised for they have a definite scientific value. Observations made in their course are likely to reveal many features which would not be noticeable from the ground. To be too close to an object is often a disadvantage, and geologically speaking, one can often see faults better from a distance!

ACKNOWLEDGEMENT

Before ending, I should also like to pay a tribute to the dauntless spirit of the R.I.A.F. officers, who piloted and navigated the Dakota across this unfamiliar route. If the reconnaissance flight was a success, it was due as much to the geologists in the plane and good weather as to the perfect training and technical skill of our flying officers, of whom we are justly proud and in whom we repose the highest confidence.

CLASSIFICATION OF THE TASMAN GEOSYNCLINE.* BY

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(With Plates 10 to 17.)

ABSTRACT

The Tasman Geosyncline from the Upper Pre-Cambrian to Late Permian Period in Eastern Australia has been classified after applying generalizations to the criteria adopted by Kay (1951); and the study has revealed the existence of eugeosynclines, miogeosynclines, epieugeosynclines and possibly exogeosyncline. Manifestations of volcanic activity in the miogeosynclines of Eastern Australia appear to be more abundant than in North America. Serpentinous intrusions appear to exist in eugeosynclines, miogeosynclines and epieugeosynclines.

INTRODUCTION

Ever since James Hall, propounded the fundamental concepts of the Geosynclinal theory, disclosed in his Presidential Address in 1857, there have been lively discussions among geologists of many countries. Glassner and Teichert (1947) summarised the views of various geologists who have discussed the geosynclinal concept from lithogenetic, orogenetic and geotectonic aspects. The last decade has witnessed a new tectonic approach to sedimentation in and classification of geosynclines. Kay (1951) discussed the North American Geosynclines and had attempted a classification of them depending upon the types of sediments in relation to tectonic environments.

This study of the Tasman Geosyncline was made while in the Geology Department, University of Tasmania, as a Senior Fellow under the Colombo Plan. An attempt is made to classify the Tasman Geosyncline according to Kay (1951) after applying generalizations to his criteria. The record and history of the geosynclines so classified has been discussed from U. Proterozoic

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to Late Permian times with a view not only to demonstrate the relationships that existed between these geosynclines, but also to trace the evolution of the East Australian portion of the continent. This does not mean that the history of the Tasman Geosyncline was terminated by the Hunter-Bowen Orogeny, but this region appears to have behaved in a comparatively stable manner in later periods with the development of taphro-geosynclines and later order geosynclines (Kay 1951).

This paper was sent to Prof. M. Kay (Columbia University, U. S. A.) and the writer is very grateful for comments and suggestions offered by him which have been incorporated in this paper.

To illustrate the limits of the various geosynclinal belts in the Tasman Geosyncline, eight maps have been included showing the types of sediments deposited from Cambrian to Permian times. No reconstruction during the Upper Proterozoic Epoch was attempted as the information on the extent of the belts and types of sediments in Eastern Australia is not sufficient. In this connection it must be emphasized that each map is at best an imperfect attempt to synthesize stratigraphical data and this cannot be done with high degree of accuracy as sufficient data are not available.

It may be pointed out that considerable difficulty was experienced in gathering the material necessary for this study. A code of sedimentary nomenclature has yet to be adopted in Australia and this was one of the fundamental problems discussed at the Australian and New-Zealand Association for the Advancement of Science in 1952. The terms "greywacke", "spilite" and "quartzkeratophyre" have been used by different geologists in different senses. It need hardly be emphasised what great bearing the correct description of rock types has on naming the types of geosynclines, when they are being classified according to Kay. Apart from these terms, much remains yet to be done in the way of correlating the various formations before a correct picture of the geosynclines can be obtained. Another difficulty is the inadequate information on thicknesses of formations and their sedimentary characters. This is of vital importance in such a study for the purpose of correctly identifying areas of geanticlinal uplift and source areas of sediments.

ACKNOWLEDGEMENTS

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Upper Pre-Cambrian Epoch

In South Australia during Upper Proterozoic times the Flinders and Mount Lofty Ranges were sites of maximum deposition. The sediments of the Adelaide System are mainly limestones, slates, tillites, quartzites and shales with minor volcanism. Some evidence of volcanism is found among the Upper Pre-Cambrian strata at Mount Caernarvon, Wooltana, Paralana and elsewhere in the Flinders Range the rocks consisting of basic lavas with very minor agglomerates, breccias and tuffs. Spry (1950) stated " Archean basement rocks occur to the west at the Eyre and Yorke Peninsulas and to the north east at Broken Hill, along the axis of the Mount Lofty Ranges from Normanville to Houghton. To the east of this axial line, the Adelaide System rocks show abrupt lithological change and while marker horizons are recognisable 300 miles north of Adelaide, they are not found 40 miles to the east. The magnesite and tillite horizons are no longer a prominent feature and non-magnesian limestones take the place of dolomites. The basal sandstones are much thicker on the east than on the west of the Ranges. Wymond (1950)

noted the complete change in the Bulls Creek area and suggested that the axial ridge formed a barrier between the western and eastern areas of deposition. It was noted that a tremendous thickness of true greywackes appeared towards the regionally metamorphosed zone on the east of the ranges. Madigan (1925) mapped a wide area of greywackes along the south of the Fleurieu Peninsula. The axial ridge is a definite zone of weakness and if it was a dry land during Adelaide System times, then it may have formed the eastern margin of a closed basin during deposition of the magnesite, as it marks the easterly limit of the magnesitic Montacute Dolomite in the Adelaide area. There is no definite evidence that the axial ridge was uncovered during the Upper Proterozoic, and the basal beds encircle the Archean inliers. The only reason for considering a land ridge here is the change of facies to the east, although this line of weakness may have been present simply as a change of slope on the sea floor." Near the Western Queensland border there is a thick series of quartzites and conglomerates which is considered to be equivalent to the Buldiva Series. In the Cloncurry District a number of scattered outcrops of arkose, grit and conglomerate called the Mount Quamby Series have been recorded and correlated with the Buldiva. However, these do not appear to represent geosynclinal deposition but probably indicate epicontinental environmental conditions. In Tasmania, Banks (1952) stated that the Carbine Group which overlies the Davey Group is considered to belong to the orthoquartzite—limestone suite and appears to have been deposited under shallow water conditions on a slowly sinking shelf around an older Pre-Cambrian nucleus. It consists chiefly of quartzites, phyllites, dolomites and argillites. There are no known occurrences of Upper Proterozoic sediments in Victoria or in Eastern New South Wales.

It has been mentioned by David (1950, I, p. 93) that in and around Broken Hill, glaciers continued to be formed and this suggests that this area was a highland during the Adelaide sedimentation. The decrease in the thickness of sediments toward Corunna, where only 350 feet of conglomerates and grits have been recorded, appears to indicate that land lay to the west and this land Cotton (1930, p. 50) called "Yilgarnia". He also mentioned that an ancient land mass lay to the east which Mawson

(1912) named "Willyama". Sprigg (1952, p. 153) stated: "Beyond the deeper geosyncline to the east, continental Willyama extended intermittently above sea level, but sedimentation from this direction was generally unimportant until later times (principally Sturtian) when glaciation and fluvo-glaciation from times eastern highlands was in progress". The thickness of the Torrowangee Series of Upper Proterozoic age north of and around Broken Hill in New South Wales exceeds 7,000 feet and possibly 11,000 feet and the section is incomplete (Sprigg-personal communication). It appears that the eastern landmass "Willyama" of Mawson lay in this direction, and it is reasonable to assume that "Willyama" might have been a highland during the Adelaide sedimentation contributing sediments from the east. Banks (1952) stated that in Tasmania the source of the sediments is not known.

Limestones, slates, tillites, quartzites and shales west of the axial line deduced by Spry (1950) in South Australia appear to have been deposited in environmental conditions quite different from those east of the axial line where greywackes predominate so that there is a distinct change of facies across the axial line. "Yilgarnia", which appears to have been a stable landmass, had its eastern limit somewhere west of Corunna as thinning of the sediments towards the west suggests. Its southern and northern boundaries are not known, but the overlap of the Lower Cambrian over the Lower Proterozoic beds in the Yorke Peninsula indicates that this area was land during Adelaide time. Between "Yilgarnia" and the axial line connecting the tip of Fleurieu Peninsula with Broken Hill the sediments are mainly argillites and limestones. The northern extension of these sediments appears to be through the Amadeus Trough with its east-west extension along the site of the Macdonell Ranges. Regarding the Northern Territory, Noakes (1953, p. 288-289) stated "Much of the detailed history of these Proterozoic geosynclines could probably be worked out by detailed mapping aided by age determinations, but the relative age and duration of sedimentation within the three geosynclines and the tectonic history of the Lower Proterozoic in this region is not known. The orogeny about the end of Lower Proterozoic time provided the forces to complete the welding of the Pre-Cambrian rocks of the Northern Territory. Geosynclinal sedimentation in this region

ended, and the rising of new mountain chains, and the sinking of stable blocks, ushered in Upper Proterozoic or Nullagine time which, in the Northern Territory, is predominantly the history of the erosion of these mountain chains, and the deposition of the resulting sediments in epi-continental seas". The northernmost extension is therefore speculative and for the purposes of this discussion is not important. The dominance of fine grained sediments makes it clear that the source areas of these sediments were mainly of low relief during the first half of the Lower Adelaide epoch, though at first the hard quartzite and titaniferous rocks of the Barossian Complex gave rise to gravels, boulder beds and ilmenitic sands.

East of the axial line the presence of greywackes and the change of facies suggest deposition in a geosyncline different in its tectonic environment from the one west of the axial line. However, the presence of argillites, phyllites, dolomites and quartzites of Upper Proterozoic age in Tasmania appear to suggest that the tectonic conditions were rather similar to those in the geosyncline west of the axial line in South Australia. However, the extent of this belt and the relation to the one in South Australia is not known.

"Yilgarnia" would probably represent the craton at that time. The deposition of argillites and limestones with minor volcanism between "Yilgarnia" and the axial line seems to have occurred in a miogeosyncline (Kay 1951, p. 107), and the name Adelaide Miogeosyncline is appropriate. The presence of greywackes further east of the axial line suggests environmental conditions of a eugeosyncline (Kay 1951, p. 107), and the name Fleurieu Eugeosyncline is suggested. Barrier Ranges and Willyama appear to represent tectonic highlands during the Adelaide sedimentation. Along the axial line following the Mount Lofty Ranges to Broken Hill there may have been a chain of islands as suggested by Spry (1950) or a simple change of slope on the sea floor which may represent the monoclinal flexture between the miogeosyncline and eugeosyncline referred to by Kay (1951, p. 107). Sprigg (personal communication) recently stated that in the Adelaide Geosyncline as indicated by recent mapping the gradation from east to west is the most perfect of a single major unit and the line of division down the centre of Mount Lofty Ranges is fallacious. He is of the

opinion that the Kanmantoo beds are Cambro-Ordovician, not Adelaide System at all, hence differences are to be expected, but they are, however, a flysch-like development. According to Sprigg it appears that evidence for an eastern eugeosynclinal belt during this epoch is lacking in South Australia and the same is true of Victoria, New South Wales and Queensland. However, conditions in Tasmania suggest that it was the shelf to miogeosynclinal deposition which took place around an older Pre-Cambrian Nucleus.

Cambrian Period

(*See* Pl. 10.)

The exact shape and extent of the depressions in which the Cambrian sediments were laid down is largely conjectural as there are only limited occurrences of Cambrian strata in South Australia, Victoria, Tasmania, the South Coast area of New South Wales, around Brisbane and in Western Queensland. It has been mentioned by David (1950 I, p. 133) that the geosyncline crossed the continent from north to south covering most of the Northern Territory, extending a little way into Western Australia and Queensland, and occupying the eastern part of South Australia. It is, however, debatable how far most of the deposits in the Northern Territory and Western Queensland are due to geosynclinal deposition. Bryan and Jones (1946, p. 2) considered the richly fossiliferous beds of the Templeton, Georgina, Pituri and Nimaroo Series in Western Queensland to have been deposited in an extensive shallow sea produced by vertical movements of large continental areas or by eustatic changes of sea level. It, therefore, appears that although the above may not represent geosynclinal deposition, the coastal regions of Eastern Queensland probably had accumulations of deposits of a geosynclinal environment.

The Rocksberg Greenstones (Bryan and Jones 1951, p. 1) in Eastern Queensland, thought to be of Cambrian age, consist of altered basic and intermediate lavas.

In New South Wales, the Wagonga Series which occupies a strip of the south coast area from the Victorian border to Clyde River consists of black banded cherts, beds of volcanic tuff with

greywackes, phyllites and mica schists. David (1950 I, p. 124) mentioned that they are unconformable under the Upper Ordovician graptolite shales, but the definite age is not known. It is possibly Cambrian as some rock types recall the Heathcotian Series in Victoria, which consists of basic tuffs, agglomerates and lavas with basic intrusive rocks which may be related to the effusive types. (David, 1950, I, p. 118.)

In South Australia the greatest development of Cambrian strata is in the Flinders Ranges but occurrences have also been recorded in the Cape Jervis and Yorke Peninsulas. There was also deposition in the southern and north eastern parts of the Northern Territory. In the Flinders Ranges in South Australia, Cambrian sediments mainly consist of slates, sandstones, limestones and some quartzites. In the south eastern parts of South Australia, David (1950 I, p. 110) mentioned small outcrops of volcanic rocks amidst the Tertiary and Post-Tertiary sediments, mainly quartzkeratophyres thought to be of this age. Mawson and Dallwitz (1944, pp. 191-203) made a detailed petrological study of these rocks, whose outcrops are distributed over many square miles of South Eastern South Australia, and assigned a pre-Ordovician age to them. They stated "these sheared and otherwise metamorphosed keratophyric rocks are believed to represent South Australian equivalents of the 'porphyroid series' of Western Tasmania" The 'porphyroid series' in Tasmania is termed the "Dundas Group" and is Cambrian, hence the rocks in South Eastern South Australia would be of this age.

Banks (1952) stated that during the Middle Cambrian epoch conditions changed drastically in Victoria and Tasmania. The floor began to sink rapidly and the nearby land surface to rise rapidly, and the Dundas Group accumulated, characterized by greywackes, sub-greywackes with abundance of lava flows and other volcanic products (Carey 1953, p. 1112).

The thickness of Rocksberg Greenstones in Eastern Queensland is 10,000 feet (David, 1950, I, p. 124) and the Dundas Group in Tasmania is of a similar thickness (Carey 1953, p. 1108). In the Flinders Ranges in South Australia, the thickness of the Cambrian deposits is probably of the order of 26,000 feet while a New South Wales and Victoria the total thickness is not known.

It will be seen that during the Lower and Middle Cambrian the Adelaide Miogeosyncline of the Upper Proterozoic continued to receive sediments. It is, therefore, suggested that as its extent in South Australia roughly appears to be the same as in the Upper Proterozoic, the name "Adelaide Miogeosyncline" for both epochs appears appropriate. It may be pointed out that in the Upper Proterozoic, the name "Adelaide Miogeosyncline" so perhaps the highlands where the Sturtian ice-sheets were formed during the Upper Proterozoic had become reduced in height by the beginning of the Cambrian Period.

Banks (1952) suggested that as sedimentary and volcanic associations similar to those in Tasmania are known in Victoria and may extend as far north as Broken Hill and as far west as the Mount Lofty Ranges, the whole area be regarded as an eugeosyncline. The spatial relationship of this geosyncline to the Adelaide Miogeosyncline and the craton at the time is similar to that observed in other parts of the world between these geotectonic elements. The Rocksberg Greenstone and Wagonga Series in Queensland and New South Wales respectively have volcanic associations similar to Tasmania and Victoria, and so it seems likely that the eugeosyncline extended into New South Wales and Queensland.

Up to Middle Cambrian times, the positions of the craton and the Adelaide Miogeosyncline continued except that eugeosynclinal conditions extended into Tasmania in the Cambrian. In the Yorke Peninsula the overlap of Lower Cambrian beds as mentioned earlier may signify a transgression over the craton. In Tasmania, however, the Upper Pre-Cambrian miogeosyncline is overlain by a eugeosyncline during this time and therefore it is suggested that this eugeosyncline be called the Dundas Eugeosyncline. Kay (1947, p. 1293) pointed out that eugeosynclines can overlie miogeosynclines. The northern limit of the Adelaide Miogeosyncline and the eastern and northern limits of the Dundas Eugeosyncline are not known during this period.

Tyennan Orogeny

The complete absence of Upper Cambrian rocks in the Mount Lofty-Flinders Ranges and the possible existence of unconformi-

ties in the same areas suggest that orogenic forces became active at the close of Middle or Upper Cambrian time (David, 1950, I, p. 131). The whole of the Adelaide Miogeosyncline was folded and elevated accompanied by granitic emplacement and consolidated as a craton. Banks (1952) has stated that in Tasmania, eugeosynclinal deposition was perhaps interrupted by early pulses of this orogeny and certainly terminated by later phases in the Upper Cambrian when ultrabasic rocks were intruded. With the Adelaide Miogeosyncline consolidated as a craton by this orogeny, the orthogeosynclinal belt shifted eastwards during the Ordovician.

Ordovician Period

(*See* Pl. 11.)

The Ordovician deposits in Victoria consist mainly of laminated shales and slates with a predominantly graptolitic fauna. Lower Ordovician graptolitic sediments are well developed in Central Western Victoria but only sparsely in Eastern Victoria. Browne (1947, p. 625) suggested that the unconformity between the Wagonga Series (Cambrian) and the Upper Ordovician in New South Wales may indicate that the Wagonga Series shared in the Upper Cambrian diastrophism. The only occurrence of Lower Ordovician rocks in New South Wales is at Narrandera where the formation consists of slates, sandstones and quartzites with the slates containing *Tetragraptus quadribrachiatus*, *Glossograptus lincksii*, *Climacograptus* of. *antiquus* and *Phyllograptus* sp which correspond to the Darriwilian Stage in Victoria (David, 1950, I, p. 155). Elsewhere in New South Wales only the Upper Ordovician is present. The Upper Ordovician at Wellington, Mandurama, Yass, Lake George, Moruya, Cobargo and Adaminaby mainly consists of shales, clay, conglomerates and some radiolarian cherts. There are thin beds of limestone at Yass and Lake George. At Trunky, David (1950, I, p. 156) mentioned slates. The Nambucca Series of the Middle North Coast has been correlated with the Bunya Series in Queensland and consists almost entirely of shales and slates which are completely devoid of fossils.

In Queensland, the unfossiliferous Bunya Series, outcropping chiefly around Brisbane, consists of slates and quartzites with beds of phosphatic cherts and is considered to be Upper Ordovician (Bryan and Jones, 1946, p. 22). Sedimentary and metamorphic rocks resembling the Bunya Series have been recorded from the Leichhardt Ranges and between Emerald and Clermont and elsewhere. A possible extension may be shown by the rocks of Townsville, west of Innisfail, Cairns and Cooktown where slates and greywackes are predominant. The Toko Series occurring on the western border of Queensland is fossiliferous and made up of horizontal calcareous and arenaceous sediments which do not appear to represent geosynclinal deposition.

In Tasmania, the Ordovician rocks (Junee Group), as mentioned by Carey (1953, p. 1109), fringe the main Pre-Cambrian belt and consist of the Jukes Breccia, West Coast Range Conglomerate, Caroline Creek Sandstone and the Gordon Limestone laid down after the intervention of the Tyennan Orogeny.

In Tasmania, the Jukes Breccia and the West Coast Range Conglomerate suggest that the Tyennan mountains were fairly high but by the Arenigian the presence of Caroline Creek Sandstone and the Gordon Limestone indicates that the Tyennan mountains had been almost worn down. Banks (1952) stated "Preliminary observations suggest that the sediments in the Caroline Creek Sandstones were derived from land surface to the west and to the east or north-west". Since the limestones in Tasmania are a facies variant of the Ordovician System in Victoria where the main rock types are clastics, it seems possible that the land surface, the craton, lay to the west. The complete absence of conglomerates in Victoria and New South Wales in this geosyncline shows that the physiography of the source areas of sediments was not of marked relief.

The total thickness of the Ordovician System in Victoria was given by David (1950, I, p. 146) as 15,000—20,000 feet. In New South Wales at Goulburn 12,000 feet, and at Trunkey about 8,000 feet of probable Ordovician strata are mentioned. The Bunya Series in Queensland is estimated at 18,000 feet. At the Mount Wellington anticlinorium in Victoria 10,700 feet has been recorded and in Tasmania the thickness of the Junee Group is of the order of 7,000 feet.

The western limit of the Lower Ordovician sedimentation is conjectural and the cratonic edge is thought to be somewhere near the present South Australian-Victorian border. The South Coast area in New South Wales may have been highland during the Lower and Middle Ordovician sedimentation as there is evidence of unconformity between the Cambrian and Upper Ordovician. The predominant development in Victoria of shales and slates which are facies variants of the Ordovician Limestones, in Tasmania, and thin developments of limestones in New South Wales suggest that miogeosynclinal conditions existed. Its eastern limit appears to be roughly along a line in New South Wales a little east of Wellington and Moruya and near Trunkey. At Trunkey, as mentioned earlier, there is a development of greywackes which suggests that probably eugeosynclinal conditions existed there and east of it, whereas to the west at Yass and at Lake George thin development of limestones appears to indicate a miogeosynclinal environment. Banks (1952) also stated that the sedimentary structures both in Victoria and Tasmania suggest deposition in a miogeosyncline. He called this the Gordon Miogeosyncline and its extension is the miogeosynclinal area in New South Wales, but the probable extension into Queensland is not known exactly. There are no recorded occurrences of greywackes from the Bunya or the Nambucca Series, but they are completely unfossiliferous indicating different environmental conditions in this eastern region. Moreover, the occurrences of greywackes at Cairns, Cooktown and Innisfail in Northern Queensland have been correlated with the Bunya Series and suggest eugeosynclinal deposition to the east. Therefore, taking into consideration the unfossiliferous nature of the sediments and the occurrence of greywackes in Northern Queensland, the existence of an eugeosyncline in the eastern region is indicated and it is suggested that this be called the Bunya Eugeosyncline. This eugeosynclinal reconstruction receives support from Kay (1951, p. 66). As explained earlier the Bunya Series is correlated with the greywackes in North Queensland and the Nambucca Series is correlated with the Bunya and therefore the assumption of eugeosynclinal conditions appears to be reasonable. In the Gordon Miogeosyncline there are some occurrences of volcanics. David (1950, I, p. 171) pointed out that when both the thickness and extent of the

Ordovician sediments are considered the manifestations of contemporaneous volcanic activity are astonishingly few. Kay (1951, p. 66) stated that the geosynclines or geosynclinal sediments in the two sorts of belts were not always exclusive at their boundaries, though their extremes contrasted sharply. The presence of volcanics, therefore, in the Gordon Miogeosyncline does not in any way affect its tectonic environment which is miogeosynclinal. At the close of the Ordovician, the orthogeosynclinal belt appears to have occupied the previous position of the Dundas Eugeosyncline in the Cambrian.

Benambran Orogeny

The Ordovician Period closed with the elevation of a geanticline along a submeridional axis accompanied by the emplacement of synchronous batholiths. This geanticline appears to have extended from Bindi in the Tabberabbera district through the Mitta-Mitta River in Victoria, passing through Holbrook, Junee, Temora, and Condobolin in New South Wales. It is not known how far north it may have extended. Andrews (1938, p. 151) called this the Mitta-Mitta Geanticline. It appears that west of the Mitta-Mitta Geanticline more geanticlines might have been developed with basins in between. However, the present data regarding thickness of sediments and their character are not adequate to locate the minor swells. The Mitta-Mitta Geanticline and subsidiary geanticlines evolved in the orthogeosynclinal belt of the Ordovician.

In Queensland, Jones (1953, p. 693) stated "The evidence for this and the Benambran Orogeny has emerged during the preparation of a new geological map of Queensland. The strongest line of evidence is that the Burdekin River, Fanning River, and the Reid Gap limestones and other associated sediments of Givetian age everywhere rest on pre-Devonian rocks with a strong unconformity". There is no reason why the orogeny should be Benambran, it could as well be Bowning (late Silurian) and from a study of the Tasman Geosyncline it appears to be the latter, for there seems to be a change in the nature of sedimentation in Queensland during the early Devonian as pointed out on a later page.

Silurian Period

(*See* Pl. 12.)

On either side of the Mitta-Mitta Geanticline, deposition continued into the Silurian without a break. However, after the Benambran Orogeny the character of the sediments on either side of the Mitta-Mitta Geanticline was different from that of the Ordovician as will be seen presently.

In Victoria, west of the Mitta-Mitta Geanticline, a sudden change in the environment of deposition is reflected by the presence of green and coarse-grained Keilorian sediments in contrast to the fine grained carbonaceous shales and mudstones of the Upper Ordovician. The main rock types are shales, mudstones, sandstones and conglomerates with minor bands of intercalated limestones.

In Tasmania also, there is a sudden change in sedimentation, the Gordon Limestone of the Ordovician being followed in the Silurian by the Crotty Quartzites of the Eldon Group. This group was deposited in Tasmania west of the Mitta-Mitta Geanticline and consists of shales, quartzites and slates with some limestones.

East of the Mitta-Mitta Geanticline there is a change of facies. David (1950, I, p. 192) mentioned occurrences of fossiliferous Silurian rocks from Cowombat, Mitta-Mitta River, Gibbo River and elsewhere and stated that these show a clear and close resemblance to the Middle and Upper Silurian faunas further north but, on the other hand, they have nothing in common with the faunas situated west of the Mitta-Mitta Geanticline. This leads one to infer that they represent, in part at least, an eastern limestone facies equivalent to that of the Melbournian sandstones and mudstones further west. The sediments in the geosyncline immediately east of the Mitta-Mitta Geanticline consist chiefly of conglomerates, sandstones and shales with a predominant development of coralline limestones. In addition, volcanism appears to have played some part as shown by the basic and acid lavas recorded from Trunkey, the Molong-Wellington belt, the Bombala-Canberra region and Bathurst in New South Wales. Its northern continuation may

probably be represented in Queensland in the Broken River area where conglomerates, sandstones, shales and limestones have been mentioned by David (1950, I, p. 202). The total thickness of the Silurian sediments in New South Wales is not known.

Further east of this geosyncline in New South Wales, tectonic environmental conditions were very different as at Jenolan radiolarian cherts, spilites and keratophyres have been recorded associated with limestones, mudstones and shales. In the New England Plateau, jaspers, spilites, keratophyres, tuffs and breccias have been noted. Between Coff's Harbour and the Tweed river there are occurrences of greywackes, conglomerates, cherts and tuffs. This volcanic association may continue to the north in Queensland in the Neranleigh-Fernvale Series which consists of greywackes, jaspers, andesites, tuffs and quartzites. Greywackes and quartzites in the Chillagoe-Mungana area probably extending to the Palmer River and also occurring at Cooktown and Cairns might indicate the northern extensions.

Therefore, during the Silurian, sediments accumulated under different conditions, in three distinct basins:

1. Between the craton which was somewhere near the Western border of Victoria and the Mitta-Mitta Geanticline the geosyncline received the muddy, shallow-water Melbournian facies.
2. Immediately east of the Mitta-Mitta Geanticline abundant coral limestone and shales were deposited.
3. Further east, a geosyncline with typical bathyal facies, characterized by the presence of volcanics, developed.

The sediments west and east of the Mitta-Mitta Geanticline appear to have been derived from this Geanticline and the minor swells within the geosynclines. The abundance of coarse grained sediments on either side appears to suggest that the Benambran mountains forming this geanticline may have had considerable relief. In Tasmania, Banks (1952) stated " Evidence from the Eldon Group suggests that the Crotty becomes finer and thinner towards the east and is finally overlapped, showing the source of sediments to be to the west, probably from a land surface rejuvenated by the Benambran Orogeny further east.

The Mathinna Group at Scamander shows, by different sedimentary structures present, that the source of the sediment was a low lying land surface not very far to the east". With regard to the source of sediments in Victoria and New South Wales, Andrews (1938, p. 157) stated "The sedimentation in the eastern trough suggests deposition under varying conditions, clear water of shallow to moderate depth in places, coarse deposition along its western margin. Coralline growths are abundant in the eastern trough. Coarse sedimentation appears to have followed the Mitta-Mitta Geanticline in New South Wales especially along its western side". The thickness of sediments in Victoria is 24,000 feet at Meathcote, 20,000 feet at Woods Point, and between 10,000 to 15,000 feet at Lilydale, while in Tasmania the thickness is about 6,000 feet. In Queensland about 25,000 feet of the Neranleigh and Fernvale formations occur at Ipswich, and in the Broken River area 27,000 feet have been recorded.

The tectonic environment and sediments in the basin between the craton and the Mitta-Mitta Geanticline appear to indicate intramiogeosynclinal deposition (Kay, personal communication). Banks called this the "Eldon Exogeosyncline". Kay pointed out this conception of an exogeosyncline is incorrect, as it is not intra-cratonal, for it lies in the western part of the Gordon Miogeosyncline and it is therefore intra-miogeosynclinal. According to Kay (1951, p. 107) "Exogeosynclines, within cratonal borders, gain sediment from erosion of complementing highlands outside the craton in the orthogeosynclinal belts . . . ." As this basin did not lie within the cratonal border, it appears to be a part of the miogeosynclinal belt of this period. David (1950, I, p. 220) mentioned that the western limit of the Lower Silurian sea was west of the meridian of Melbourne and the sea might have stretched as far as the Walhalla Synclinorium. Mount Wellington in Victoria might have been a land area and Mount Easton an island or peninsula or perhaps a submerged reef which was not completely covered until a later date. The Mitta-Mitta Geanticline might have extended east of the present eastern coastline of Tasmania. Andrews (1938, p. 154) considered sedimentation west of the Mitta-Mitta Geanticline as having taken place in a separate geosyncline and termed it the Goulburn or the Zephyrine Geosyncline. He stated (1938, p. 157) "Shorelines and high feeding grounds appear to have existed in the Yass,

Forbes, Cobar and other western districts". However, it appears that sedimentation west and east of the Mitta-Mitta Geanticline took place in a miogeosyncline. The extension of the craton in Tasmania would presumably be west of the present coastline as sediments have been inferred to come from the west.

There is evidence of unconformity immediately west and east of the Mitta-Mitta Geanticline, though further west and east the Silurian is conformable on the Ordovician. No unconformities within the Silurian are known except for overlaps in the Walhalla Synclinorium in Victoria, where the Mount Useful beds wedge out on the western side and the Jordon River Series rests on Upper Ordovician. The type of sediments deposited and the tectonic position of the geosyncline west and east of the Mitta-Mitta Geanticline indicate a miogeosyncline. The abundant development of limestones with corals also suggests such an environment. Andrews (1938, p. 134) called the trough east of the Mitta-Mitta Geanticline the "Coralline Geosyncline". It is considered here that "Molong Miogeosyncline" would be a more apropriate name for the troughs on either side of the Mitta-Mitta Geanticline. Although there is evidence of volcanism in the localities mentioned earlier, the sedimentary characters and position suggest a miogeosynclinal nature. Kay (1951, pp. 66 and 67), discussing the relation of eugeosynclines to miogeosynclines, stated "There may be gradual diminution from thick volcanics in outer sequence to none in the inner. At times there were separating tectonic welts, some forming less subsiding strips controlling currents on depositional surfaces. others rising as highlands yielding detritus that filled miogeosynclines volcanism extended to the inner side of some such uplifts, giving eugeosynclinal sections, along the margin of strips that are otherwise miogeosynclinal". Two strips of uplift accompanied by batholithic emplacement occurred during the Benambran Orogeny, one along the Mitta-Mitta Geanticline and another east from Cooma to Canberra and probably beyond, with perhaps other minor swells feeding the Molong Miogeosyncline, so it is reasonable to apply Kay's suggestion stated above and assume that volcanism extended along these uplifts giving volcanic sections in what was otherwise a miogeosynclinal belt. The presence of conglomerates, sandstones, shales and limestones in the Broken River are in

Queensland may possibly represent its northern continuation. Its eastern limit would be roughly a line passing north of Moruya, near Jenolan and perhaps east of Cudgegong. The presence of limestones, mudstones and shales with radiolarian cherts, spilites and keratophyres at Jenolan in New South Wales might be a transition from the miogeosynclines to a eugeosyncline to the east. In Queensland the western limit of the Molong Miogeosyncline is not known and is merely conjectural, but its eastern limit appears to be near a line drawn through Chillagoe-Mungana—Palmer River because here too, as at Jenolan in New South Wales, there appears to be a transition zone from miogeosynclinal conditions to a eugeosyncline to the east where greywackes, jasper and cherts are associated with limestones, slates and quartzites.

East of the Molong Miogeosyncline, the Woolomin Series in New England and the North Coast area of New South Wales extending into Queensland consists of greywackes, spilites and keratophyres. This suggests that eugeosynclinal conditions extended into northern Queensland. As the extent of eugeosynclinal conditions in Eastern Australia appears to be roughly the same as in the Ordovician Period it is suggested that this may be called the Bunya Eugeosyncline during this period also. It appears, therefore, that the Benambran Orogeny did not affect this geosyncline. Thus at the close of the Silurian period the craton was somewhere east of the western border of Victoria its northern and southern limits being conjectural. The Molong Miogeosyncline extended into Tasmania, Victoria, New South Wales and Queensland and east of this lay the Bunya Eugeosyncline. An island appears to have existed, during this period, in the Shoalhaven Valley in New South Wales as Upper Devonian rocks are unconformable on Ordovician.

Bowning Orogeny

There does not appear to be much evidence with regard to change of sedimentary and tectonic environment in most of the Molong Miogeosyncline and the Bunya Eugeosyncline. However, in Queensland during the Lower and Middle Devonian, there appears to be a definite change in sedimentation as the area of eugeosynclinal deposition moved further east of the Cape Yorke

Peninsula region. Due to this orogeny, in New South Wales, there were emplacements of synchronous batholiths in the Molong Miogeosyncline and probably in the Bunya Eugeosyncline in New England.

The Bowning Orogeny does not appear to have affected deposition in the respective geosynclines of the Silurian Period to any great extent. Therefore, the types of sediments deposited in these geosynclines are described in the next section.

Lower and Middle Devonian Epochs

(*See* Pl. 13.)

During this period, west of the Mitta-Mitta Geanticline in the Molong Miogeosyncline, limestone, conglomerates and mudstones were deposited. Banks (1952) stated "The increasing importance of fine grained sediments in the higher parts of the Siluro-Devonian system both in Tasmania and Victoria and the presence of Lower Devonian limestones in both States indicate that land surfaces to the west and the Benambran mountains to the east were being gradually worn down". In the area east of the Mitta-Mitta Geanticline the development of limestones suggests that the land surfaces were not of considerable relief.

In New South Wales islands may have been formed by the Bowning Orogeny as at Orange, Goulburn and Bombala in which places there is definite evidence of Upper Devonian beds resting unconformably on Silurian and older rocks. The main deposits in the area east of the Mitta-Mitta Geanticline in the Molong Miogeosyncline during this period were limestones, tuffs, shales, quartzites and conglomerates, and in Victoria, the Buchan Series consists of tuffs, agglomerates, grits, sandstones and limestones Volcanic activity is also known in some places as at Mount Elizabeth, Mount Cobberas and Mitta-Mitta and Dark Rivers in Victoria. The occurrence of Snowy River Porphyrites was mentioned by David (1950, I, p. 231) who regarded them as resulting from sub-aerial eruptions from volcanic centres arranged along fissures on a subsiding coastline. This would probably be along the Mitta-Mitta Geanticline and other geanticlines uplifted during the Bowning Orogeny. As in the Silurian, this would give volcanic sections in what was otherwise a miogeosynclinal

belt. At Jenolan, hard black chert containing radiolaria and sponge spicules, and banded in places with thin layers of tuff was considered by David (1950, I, p. 225) to resemble the Tamworth Series in New England, which consists mainly of cherts, spilites and agglomerates, deposited in the Bunya Eugeosyncline. Since the rocks at Jenolan, as stated above, are considered to resemble the Tamworth Series which is characteristic of eugeosynclines then presumably the same conditions also existed at Jenolan. The position of the craton, the Molong Miogeosyncline and Bunya Eugeosyncline in the south remained just the same as in the Silurian. However, to the north in Queensland the presence of limestones, quartzites, mudstones and shales at Clermont, Mount Wyatt, Burdekin Valley and Gilberton indicates a change from the eugeosynclinal conditions of the Silurian to miogeosynclinal conditions, probably representing the northern continuation of the Molong Miogeosyncline in the Lower and Middle Devonian. The position of the Bunya Eugeosyncline appears to have been shifted eastwards, as andesites and agglomerates are recorded at Warwick, and in the Gladstone—Etna belt the Mount Etna Series with its andesites, cherts, spilites and greywackes indicates eugeosynclinal conditions and probably the continuation of the Bunya Eugeosyncline during this period. The limits of the Molong Miogeosyncline and the Bunya Eugeosyncline in Queensland are conjectural since during these epochs sufficient data are not available, but the boundary between them would be somewhere east of Clermont and west of Mount Etna.

The total thickness of sediments deposited at Yass, in the Molong Miogeosyncline, is of the order of 14,000 feet of Lower and Middle Devonian strata. The thickness of the sediments of the Mount Etna Series is about 15,000 feet in the Bunya Eugeosyncline.

Tabberabberan Orogeny

Banks (1952) stated that the Tabberabberan Orogeny halted deposition in the trough west of the Mitta-Mitta Geanticline and there is no further evidence of deposition in Tasmania until the Permian Period. This orogeny presumably had several pulses. and in Queensland, according to Hill (1951), four great "highs" and three great "lows" were formed. Most of the serpentinous

intrusions have been ascribed to this epoch. It is not definitely known if granites were emplaced in Queensland during this orogeny though Hill (personal communication) suggested that there are grounds for considering some granites occurring in the highs to be of this age. Granites were emplaced in Tasmania, Victoria and some areas in New South Wales. David (1950, I) and Browne (1949) assigned a Kanimblan age to most of the Victorian and Tasmanian granitic emplacements and connected mineralization. The palaeogeography and tectonic history, however, appear to suggest that most of the granitic emplacements and mineralization in Victoria and Tasmania are due to the Tabberabberan Orogeny.

Upper Devonian Epoch

(*See* Pl. 14.)

The condition prevailing in Eastern Australia during Upper Devonian time were in marked contrast to those of the preceding epochs. Large tracts of Lower and Middle Devonian beds were completely eroded away and many of the granites laid bare before sedimentation began (David, 1950, I, p. 276). The Upper Devonian sea had a great lateral extent and its sediments were remarkably uniform throughout, suggesting that its surface might have been diversified by islands resulting from the original configuration of submerged lands (David 1950, I, p. 276).

In Tasmania, no Upper Devonian deposits are known and it is possible that most of the State was consolidated as a craton after the Tabberabberan Orogeny. In Victoria, deposition was mainly lacustrine. The Grampian Series in Western Victoria has been shown as Upper or Middle Devonian in a map recently published by the Geological Survey of Victoria. In other parts of Victoria the deposits were mainly conglomerates and sandstones with some mudstones accompanied by contemporaneous, dominantly acid, volcanism. In New South Wales, there is evidence of partly lacustrine and partly marine conditions accompanied by some aridity. The deposits of the Lambian Series are mainly conglomerates, shales, mudstones and quartzites with red colouration and ripple marks suggesting shallow water deposition. There are occasional developments of coral

bearing limestones as at Cudgegong. However, there is a belt from Nundle through Tamworth, Bingara and Warialda where the Barraba Series of agglomerates, spilites, radiolarian cherts and tuff is known. David (1950, I, p. 252) suggested the presence of temporary volcanic islands on a shallow sea floor. East of Ashford and in Armidale, there is no evidence of Upper Devonian deposition. Voisey (1936) did not mention any occurrence of Upper Devonian in the Drake District.

In Queensland the picture is rather more definite. The Tabberabberan with its several pulses gave rise to four great "highs" and the "lows" between them (Hill, 1951). The structural geology of Queensland has been worked out by Hill (1951) and it is not necessary to go into great detail here. The writer has accepted the position as stated by Hill (1951). In the Drummond Basin were deposited sandstones, shales and conglomerates of prevailing reddish or chocolate colour with ripple marks, recalling Lambian conditions in New South Wales. In the Star and Hodgkinson Basins conglomerates, sandstones and greywackes are recorded. There is also evidence of contemporaneous volcanism in the Hodgkinson Basin. It is not known if the Bowen Basin was in existence during this time as little is known about the exact time of its origin. The Drummond, Star and Hodgkinson Basins have been collectively called by Hill the "Jack Basin". This was separated from the Bowen Basin by the North Coastal High which probably extended south and was continuous with the Anakie High. In the Rockhampton area the Berserker Series of andesites and agglomerates was deposited in Hill's Yarrol Basin which in turn was separated from the Bowen Basin by the Gogango High and bounded on the east by the south Coastal High. These "Highs" of Hill are geanticlinal uplifts.

Regarding the sediments deposited in Victoria and in New South Wales in the Lambian sea, it appears that miogeosynclinal conditions prevailed during this period. The sediments were derived from the craton to the west and also from uplifts within the previous orthogeosynclinal belt. The presence in Victoria of 1,000 feet of conglomerates at Gisborne and 800 feet of conglomerates and pebbles at Mount Wellington suggests high relief. In New South Wales conglomerates are known, suggesting that

in the Lambian sea there were some areas of considerable relief. At Cudgegong, however, there are developments of limestones suggesting an off shore facies. The thickness of the Grampian Series in Victoria is 2,000 feet and its true nature is not known, it might be an intracratonic geosyncline but sufficient knowledge of thickness and other sedimentary characters is lacking and its proper tectonic setting is difficult to determine. In the Gisborne area, 1,000 feet of conglomerates and sandstones resting unconformably on Ordovician rocks might imply transgression over a probable tectonic land.

The type of deposit in the Drummond Basin in Queensland is similar to the Lambian Series in New South Wales suggesting a northerly extension. The presence of greywackes in the Star and Hodgkinson Basins and their continuity with the Drummond Basin also suggest miogeosynclinal environment. The Jack Basin is situated between the craton to the west and the North Coastal and Anakie Highs to the east deriving its sediments from these highs or geanticlines. The presence of conglomerates suggests high physiographic relief. The sediments of this period in the Bowen Basin are not known and it cannot be stated with any certainty whether this was a scene of active deposition or not Since the Lambian sea appears to have been widespread it is herein proposed that the geosyncline in which deposition occurred, in Victoria, New South Wales and the Jack Basin of Queensland be called the Lambian Miogeosyncline. The thickness of sediments is variable from place to place but David (1951, I, pp. 253 & 254) mentioned 21,000 feet in the Hodgkinson and 5,000-7,000 feet in the Drummond Basins respectively. Basic lavas are known from many places in the Lambian Miogeosyncline and these are presumably related to the uplift in the Tabberabberan Orogeny. In New South Wales the craton was subjected to a marine transgression which perhaps approached very near to the South Australian border for in the Canbelego area Upper Devonian beds are unconformable on Silurian rocks. The cratonic edge would be probably the same as during the Lower and Middle Devonian Epochs, but the eastern limit of the Lambian Migoeosyncline is conjectural probably passing north of Glouchester in New South Wales, west of Tamworth and Bingara and joining on to the Gogango High in Queensland.

East of the Lambian Miogeosyncline tectonic conditions were different in both Queensland and New South Wales. The Gogango High as it passed south from Queensland presumably plunged below sea level being represented in New South Wales by temporary volcanic islands in a shallow sea. The Yarrol Basin probably continued into New South Wales and within it the Barraba Series was laid down. The North Coast of New South Wales and some parts of the New England Plateau may have been a highland presumably continuous with the South Coastal High in Queensland. David (1950, I, p. 271) stated "The granite boulders in the Upper Devonian Baldwin agglomerates north of Tamworth may likewise have been derived from Tabberabberan granites". The source of sediments is not known but this probably indicates that the South Coastal and Gogango Highs might have continued into New South Wales. Hill (1951) attributes the serpentinous intrusions in the Highs in Queensland to the Tabberabberan Orogeny. Thus the Yarrol Basin probably overlaid earlier serpentinous intrusions into an eugeosyncline between two tectonic lands—the Gogango High to the west and the South Coastal High to the east—which suggests that it was an Epieugeosyncline of Kay (1951). It is proposed to name this linear basin the Yarrol Epieugeosyncline. During this time it was filled mainly with lavas andesites and agglomerates estimated to be 8,000 feet at Rockhampton. However, in New South Wales, the Yarrol Epieugeosyncline did not overlie an earlier serpentinous intrusion, but appears to have been on the general trend of the Yarrol Basin of Queensland. The question arises whether this is to be classified in New South Wales as an eugeosyncline or an epieugeosyncline. The sudden change from an epieugeosyncline in Queensland to an eugeosyncline in New South Wales appears more artificial than natural. Probably the age of serpentinous intrusions in Queensland and New South Wales does not agree and hence the discrepancy. Since the sedimentation in New South Wales appears to be continuous with the Yarrol Basin in Queensland it has been suggested that it is also an epieugeosyncline. Hill (1951) called the Yarrol Basin an "Idiogeosyncline". Kay (1951, p. 77), pointed out that the late Mesozoic and Tertiary geosynclines of California have been considered to be idiogeosynclines but he doubts whether they correspond to this. He stated "typical idiogeosynclines

were broad downfolds or trenches lying cratonward from the inner arc of volcanoes in the East Indies far north of the negative anomalies strip and supposed tectogene. The late Mesozoic geosyncline of California was a linear downfold containing in its earliest stages spilitic lavas and radiolarian cherts and flanked by mid-Mesozoic ultrabasic intrusions, thus in the supposed tectogene strip it is an eugeosyncline bearing the position of a geotectoline. The structural depressions in the Tertiary in the same trend were margined by blocklike belts of less subsidence and have been considered to be epieugeosynclinal, like those in the Carboniferous of Nova Scotia . . . . Thus idiogeosynclines formed broad trenches on the opposite side of the belt of volcanoes, from the tectogene, whereas the epieugeosynclines of the California Tertiary formed more as blocks in a relatively consolidated basement overlying the earlier tectogene. They resemble the typical rift block bounded Taphrogeosynclines more than the idiogeosynclines". A similar explanation is offered with regard to the Yarrol Basin. In the early stages from the Ordovician to the Middle Devonian, as we have seen, the area was an eugeosyncline. After the Tabberabberan the basin came into existence flanked on both sides by ultrabasic intrusions, similar to the Late Mesozoic and Tertiary Geosyncline in California described by Kay (1951). It is a linear basin overlying an earlier eugeosyncline with serpentinous intrusions. Therefore, it is considered fitting to regard the Yarrol Basin as an epieugeosyncline rather than an idiogeosyncline as suggested by Hill (1951).

The extension of the South Coastal High in New South Wales is conjectural as there has been no definite evidence of Upper Devonian deposition in the North Coast area and in parts of the New England Plateau. Andrews (1938, p. 162) in his reconstruction also envisaged terrestrial conditions in this region.

Lower Carboniferous Epoch

(*See* Pl. 15.)

There is evidence of some movement between the Upper Devonian and Lower Carboniferous Epochs. This perhaps may signify the early pulses of the Kanimblan Orogeny. Carey and

Browne (1938, p. 603) mentioned that the Upper Devonian beds were folded along a general northwest direction at the close of Devonian time, but this folding does not appear to have extended to the Great Serpentine Belt and the basal conglomerate at Babbinboon was probably derived from erosion of land lying to the west. They concluded that Epi-Devonian movement appears to be confirmed in New South Wales. It would, therefore, appear that the Lambian Miogeosyncline in New South Wales and also in Victoria was elevated during this epi-Devonian movement. However, the Jack and Yarrol Basins of Hill received sediments during this time.

The Lower Carboniferous edimentation began with the Lower Burindi Series in New South Wales. The whole thickness of the Lower and Upper Burindi in the serpentine belt is estimated to be 1,500 feet increasing to 5,000 to 8,000 feet towards the west (David 1950, I p. 228). The Burindi sedimentation took place in the Yarrol Epieugeosyncline, in New South Wales. The rocks are greenish to greyish mudstones and shales varied by bands of felspathic tuff and some breccia with a few lava flows at the top of sequence. Carey and Browne (1938, p. 603) stated that Benson had demonstrated that there is no evidence in the Great Serpentine Belt of a break between the Upper Devonian Barraba series and Burindi series, in fact the two series are almost indistinguishable lithologically. Further west, Carey (1937, p. 350) found, on the western limb of the Werrie Syncline, that the base of the Burindi is marked by a heavy conglomerate though no angular unconformity was observed. The presence of conglomerates probably signifies epi-Devonian movements in the Lambian Miogeosyncline.

At the close of Lower Burindi time there appears to have been another movement which raised some parts of the area of marine sedimentation above sea level in the Yarrol Epieugeosyncline in New South Wales. This has been called the Wallarobba Movement (Carey and Browne 1938, p. 603) and its incidence is marked by a change from marine to terrestrial facies along a strip extending from Babbinboon to the Lower Hunter Valley where the base of the Lower Kutting is marked in a number of places from Clarencetown to Babbinboon by heavy conglomerate. As indicated by Carey and Browne (1938, p. 592) it is possible to separate an area of terrestrial deposition from

a contemporaneous one of marine deposition during Visean time so that the Lower Burindi passes upwards into Lower Kuttung in the type area in the Hunter Valley. There are indications of minor oscillations as evidenced by the presence of *Lithostrotion* limestones at Taree and Babbinboon. The areas of terrestrial deposition during the Lower Kuttung are characterised by volcanic lavas of great variety. Voisey (1945, p. 38) mentioned that only in the Rocky Creek and Gloucester areas have lavas been associated with marine sequences of Visean age in New South Wales and that it would seem that centres of volcanic activity ran parallel to the strand line and were more or less restricted to the coastal strip.

No Carboniferous rocks are known in Tasmania and Browne (1947) stated that the Lower Carboniferous rocks of Victoria are entirely terrestrial. Therefore, Tasmania, Victoria and a greater part of New South Wales appear to have subsided very little during this period.

In Queensland, the Drummond Series consisting of green and purple shales interbedded with and overlain by buff sandstones was deposited in the Jack Basin and at Elgin Downs 50 miles north-west of Emerald equivalent beds occur. At Mount Wyatt, the Upper Devonian beds are followed conformably by more than 1,000 feet of unfossiliferous sediments and on Cape York Peninsula, in the Pascoe River area, there are ferruginous sandstone, grits, shales and volcanic rocks. The presence of fine grained sediments during this period indicates lands of low relief. As in the Upper Devonian, the Jack Basin continued as a miogeosyncline but its limit was restricted by the elevation of the Lambian Miogeosyncline in Victoria and New South Wales. It is, therefore, proposed to call this depositional area the Jack Miogeosyncline. The type of sediment in the Bowen Basin is not known even during this period.

In the Yarrol Epieugeosyncline, tectonic conditions were different from those in the Jack Miogeosyncline. The Rockhampton Series in Queensland which consists of calcareous grits banded cherts, mudstones, shales, sandstones and conglomerates with andesite lavas and tuffs was deposited in this Epieugeosyncline and appears to be conformable on the Upper Devonian. The mudstones and limestones near Texas in this geosyncline

are probably the northern continuation of the Burindi bed at Ashford (New South Wales). In the Mudgeldie Goldfields conglomerates, sandstones, limestones, greywackes and acid to basic volcanic rocks have been recorded, and at St. Helens agglomerates, andesitic tuffs, thin limestones and sandstones have been noted. The thickness of the Rockhamton Series is given by David (1950, I, p. 287) as about 14,000 feet and is considered to be the stratigraphical equivalent of the Lower and Upper Burindi Series in New South Wales, and therefore the Yarrol Epieugeosyncline continued uninterrupted in this period in Queensland and New South Wales.

The thickness of Lower and Upper Burindi sediments in New South Wales between the Manning and Karuah Rivers is of the order of 12,280 feet, whereas in the Macleay Valley it is only a little over 4,000 feet (David 1950, I, p. 290). As mentioned earlier, the total thickness of Lower and Upper Burindi in the Great Serpentine Belt is 1,500 feet and this increased westwards to 5,000-8,000 feet thus suggesting an area of elevation in the New England Plateau and North Coast area of New South Wales. This would be the extension of the South Coastal High in Queensland and it may have been submerged or stood out as highland. It has been mentioned by David (1950, I, p. 290) that in various parts of the New England Plateau are scattered outcrops of beds which may be of Burindi or possibly Devonian age, though no conclusive fossil evidence has so far been obtained from them. However, conglomerates are present both in the Macleay Valley and between the Karuah and Manning Rivers, which suggests that sediments were probably derived both from the north and northeast and also from the west and southwest. Moreover, the thinning of the Lower and Upper Burindi towards the east and northeast and thickening towards the west and southwest appears very significant and it is logical with this evidence to assume the extension of the South Coastal High in that region.

At the close of the Lower Carboniferous, the craton had enlarged and its edge in New South Wales would be somewhere west of Maitland and the Namoi River. Stevens (1950, p. 331) stated that in the Canowindra district of New South Wales, Lower Carboniferous tuffs and mudstones conformably overlie the Upper Devonian rocks. The base of the Lower Carboniferous

is marked by a conglomerate horizon. The deposition of these sediments probably took place on the craton. The position of the craton in Queensland is conjectural. The Jack Miogeosyncline in Queensland had a limited extent but the Yarrol Epieugeosyncline continued during this period. However, in New South Wales in the Yarrol Epieugeosyncline there is evidence of movements that brought the Wallarobba Ridge close to the craton. The South Coastal High also continued in Queensland and New South Wales but nothing is known about the Bowen Basin even if it did exist during this time. The Carboniferous deposits at Mansfield in Victoria by their position and environment suggest an intracratonic geosyncline but details of thickness and relationship with the craton of that time are not sufficient to classify it definitely.

Kanimblan Orogeny

The first pulse was perhaps the epi-Devonian movement in New South Wales. Its later pulses may have been the cause of the elevation of the Wallarobba Ridge and the oscillations between terrestrial and marine conditions in the Taree-Babbinboon strip. The last phase was probably the Drummond movement in Queensland adding the Jack Miogeosyncline to the craton, and also bringing about major changes in the relations of land and sea in the beginning of the Upper Carboniferous period in New South Wales. Hill (1951) stated that in Queensland the eastern edge of the craton was then to the east of a line drawn from Clermont to Ayr and the whole of Queensland north of the 20th parallel was continental. This assumes existence of the Bowen Basin.

In Queensland and New South Wales a number of batholiths have been proved to be due to the Kanimblan Orogeny, but there is confusion as to which of the granitic emplacements in Victoria and Tasmania are to be assigned to this epoch. David (1950) and Browne (1949) were inclined to attribute most of them to the Kanimblan Orogeny but as Carey (1952, p. 1113) pointed out, the termination of a long period of sedimentation marked by the absence of post-Lower Devonian sediments in Tasmania, suggests that deposition was cut off by the Tabberabberan Orogeny, while in Victoria no evidence has yet been produced

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to prove that any of the granitic emplacements and ore genesis are later than the Tabberabberan. Indeed, from a tectonic analysis, most of the granitic emplacements and ore geneses in Victoria and Tasmania appear to belong to the Tabberabberan rather than the Kanimblan Orogeny.

Upper Carboniferous Epoch

(*See* Pl. 16.)

Major changes in the distribution of land and sea took place as a result of the last pulses of the Kanimblan Orogeny. The Yarrol Basin does not appear to have extended into New South Wales and the New England High may have become a broad highland and a scene of active erosion. The New England High appears to have been formed by the merging of the Gogango and South Coastal Highs and joined on to the Wallarobba Ridge to the south. West of this highland Upper Kuttung terrestrial sedimentation took place apparently in intramontane troughs. Voisey (1945, p. 38) mentioned that the main glacial beds which follow the "main clastic zone" during the Upper Carboniferous do not appear to have been deposited over much of the area between the Karuah and Manning Rivers, *i.e.*, in the neighbourhood of the Gloucester Trough, and that this may well have been a highland formed as a result of volcanic activity and the deposition of the main clastic zone. It is noteworthy that the sediments of the Kamilaroi are also absent from this area, unless the Gloucester Coal Measures are their terrestrial equivalents (Voisey 1945, p. 38). The Upper Kuttung is composed of glacial and fluvio-glacial deposits with a considerable proportion of volcanics and is well displayed in the Lower Hunter Valley, Bingara, Werrie, Muswellbrook and elsewhere. However, east of the New England Highlands marine conditions are observed at Taree, Kempsey and Drake. At Taree the Kullatine Series is estimated to be 1,340 feet but it thickens westwards where the proportion of tillite increases to make up three quarters of the whole succession. This suggests that there was a landmass to the west the New England Highlands. In the Drake District. the Emu Creek Series which is marine, consists of fine grained tuffs and tuffaceous sandstones with thin conglomeratic bands. The descriptions given by Voisey (1936, p. 157) seem to suggest

that they are greywacks. This suggestion was confirmed by Spry (personal communication) who had seen the rocks. David (1950, I, p. 294) mentioned a number of isolated occurrences of lavas of Upper Kuttung age scattered over the New England Plateau at Emmaville, Glen Innes and other places and these indicate terrestrial deposition in those areas.

In Queensland, the Neerkol Series is considered equivalent to the Kullatine marine series in New South Wales. In the type area at Stanwell, it rests conformably on the Rockhampton Series and consits of a basal conglomerate succeeded by greenish mudstones with interbedded grits. Similar beds have been found in Northbrook, northwest of Fernvale and also at Mount Barney. Elsewhere in Queensland extrusion of volcanic rocks took place on the craton. The history of sedimentation in the Bowen Basin is still obscure though Hill (1951) stated that the Bowen Basin began at least to downwarp at the beginning of the Permo-Carboniferous Period.

The thickness of Upper Kuttung in the Lower Hunter Valley is estimated to be 4,300 feet, though it varies from place to place. The Kullatine Series at Kempsey, New South Wales, is not less than 5,000 feet and about 4,500 feet of Neerkol beds have been recorded at Stanwell in Queensland.

Regarding the palaeogeography of this period, terrestrial deposition took place from the Lower Hunter Valley to Bingara and a little beyond in intramontane troughs and the presence of coarse grained sediments suggests lands with high relief. The Yarrol Epieugeosyncline, after the final phase of the Kanimblan Orogeny, does not appear to have extended into New South Wales. The presence of angular discordance between Burindi deposits and the Permian Coal Measures at Ashford suggest that during this period Ashford remained a land area. The Gogango and South Coastal Highs appear to have merged after the Kanimblan epoch, giving rise to the New England Highlands joining with the Wallarobba Ridge to the south. The presence of Upper Kuttung rocks at Emmaville and Glen Innes in New South Wales, and the Stanthorpe-Ballendeen area in Queensland suggests terrestrial conditions. The New England Highlands would appear to begin just north of Gloucester, pass west of Taree and east of Emmaville and join the western limb

of the South Coastal High. David (1950, I, p. 295) mentioned that glaciers came down to the sea in the Lower Manning area, so the sea must have been as far west as Nowendoc. The probable western limit of the New England Highlands is an arc from Port Stephens passing east of Warialda. West of this lay the Upper Kuttung intramontane troughs and the craton. East of the New England Highlands lay the area of marine sedimentation at Taree, Kempsey and Drake in New South Wales and in Northbrook and Mount Barney in Queensland. This is probably the Esk Basin. of Hill (1951) who stated that traces of marine Permo-Carboniferous sediments are known along the margins of the Esk Basin which presumably started to downwarp during this period. In Queensland, the Esk Basin Overlaid an earlier serpentinous intrusion but in New South Wales it was bounded to the west by the New England Highlands and to the east by the eastern arm of the South Coastal High which must have had an extension outside the present eastern coastline of New South Wales. This suggests that it might also be an epieugeosyncline and therefore it is proposed to call it the Esk Epieugeosyncline. The tectonic position of the Bowen Basin in the framework is not known and neither is its relation to the intramontane troughs in New South Wales. The Silver Valley Series in Queensland is composed of continental volcanics. The Yarrol Basin continued as an epieugeosyncline though restricted in its extent. Tasmania, Victoria, a major portion of New South Wales and the Drummond Ranges in Queensland behaved as a craton.

Permian Period

(*See* Pl. 17.)

There is no evidence of an orogenic break between the Kanimblan and the Hunter-Bowen disturbances, though Browne (1947, p. 632) suggested that there is much evidence of vertical movement. During this period the Bowen Basin downwarped between the craton and the Gogango High and attained maximum development. Its deposits include conglomerates, sandstones, shales, limestones and some acid and basic lavas. Simultaneously, in New South Wales immediately west of the New England Highlands, the Hunter Valley downwarped, its deposits being mainly conglomerates, shales, sandstones, mudstones,

limestones and some lavas. Coal measures were developed in both basins. The Bowen Basin in Queensland could be interpreted as an exogeosyncline deriving sediments from the craton to the west and also from the Gogango High—a geanticline raised after the Middle Devonian in an orthogeosynclinal belt. The Hunter Basin too would be an exogeosyncline deriving sediments from both the craton and the New England Highlands—a continuation of the Gogango and South Coastal Highs. Hill (personal communication) stated that the Bowen and Sydney Basins are probably continuous under the Great Artesian Basin and she distinguished the Hunter from the Sydney Basin. The writer thinks that the latter two basins are in fact one and the same and therefore it is proposed to call this exogeosyncline in Queensland and New South Wales the Hunter-Bowen Exogeosyncline. The western limit of the Hunter-Bowen Exogeosyncline in New South Wales would be along the western margin of the Goulburn River, south to the Shoalhaven River and beyond perhaps to near Mount Dromedary since there is evidence of strong unconformity of Permian over Devonian or older rocks along that line for a distance of more than 170 miles (David, 1950, I, p. 345). To the west lay the craton. Northward, its western margin would pass west of Jenolan and Liverpool Ranges probably continuing onward to join the western limb of the Bowen Basin. Its eastern limit would be the New England Highlands. The thickness of sediments at Nowra is 3,610 feet (David, 1950, I, p. 347) increasing to about 5,000 feet at Wollongong (David, 1950, I, p. 347), attaining its maximum development of a little over 17,000 feet at Lochinvar, but decreasing to 5,000 feet at Cranky Corner. To the north in the Werrie Basin 5,700 feet of Permian sediments have been measured. In Queensland, at Springsure of Cracow 10,000 feet of sediments are known increasing northwards to over 18,000 feet in the Bowen River area.

The Yarrol Epieugeosyncline continued uninterrupted during the period, its sediments being conglomerates, shales, sandstones, agglomerates and andesites. At Ashford, New South Wales, the 500 feet of conglomerates, sandstones and shales which have been mentioned, probably indicate its southernmost limit. The thickness of sediments in the Yarrol Epieugeosyncline in Queensland is 9,400 feet at the Styx River (Bryan and Jones, 1946, p. 46) and over 12,000 feet at St. Helens (Bryan and Jones, 1946, p. 46).

The Esk Epieugeosyncline continued to receive sediments in this period, its deposits being mainly conglomerates, mudstones, shales, agglomerates and limestones with acid and basic lavas. About 5,000 feet of sediments have been recorded at Drake and Emmaville.

The New England Highlands occupied probably the same position as during the Upper Carboniferous. The presence of conglomerates suggests the Highlands had a relief as high as in the previous period. Voisey (1945, p. 38) stated that the Lower Marine (Kamirlaroi) Series is absent in the neighbourhood of Gloucester, unless the Gloucester Coal Measures are their terrestrial equivalent. This seems to point to terrestrial conditions at Gloucester during this period.

The Maryborough Basin, east of the South Coastal High in Queensland appears to have downwarped during this time and its deposits are shales, sandstones, conglomerates, tuffs and greywackes. Its tectonic environment is difficult to determine. On the west it overlies earlier serpentinous intrusions but it is not known if there were any highs off the present coastline of Australia during that time. Allusion in the past to the so-called " Tasmantis " to the east might refer to possible " highs " off the present coastline in which case the Maryborough Basin would in all probability be termed an Epieugeosyncline. The problem of " borderlands " will be discussed at the end of this section. As there is some evidence of a tectonic land to the east, it is proposed that the Maryborough Basin be called the Maryborough Epieugeosyncline.

In the Silverspur area in the Yarrol Epieugeosyncline marine sediments consisting of tuffaceous shales, sandstones, glacial boulders and conglomerates have been mentioned by Bryan and Jones (1946, p. 45). The presence of 2,900 feet of submarine lavas at Warwick in Queensland might suggest that some connection between the Yarrol and Esk Epieugeosynclines might have existed.

In the Cape York Peninsula, in Queensland, freshwater deposits at Little River, Mount Mulligan and elsewhere consisting of sandstones and shales appear to be autogeosynclinal though data regarding the thickness and other sedimentary characters are not at present available. However, the deposition

took place in a distinctly cratonic area and therefore it is considered an autogeosyncline. In Victoria also, the Permian deposition appears to have probably taken place on the craton. Banks (1952) stated that in Tasmania thicker deposits of the orthoquartzite-limestone suite appear to have been derived from the surrounding craton and that there is evidence that individual formations thicken towards the axial or central part of the trough, the sediments tending to become fine grained in that direction. He concluded that the deposition was in an autogeosyncline. Later work has altered the above reconstruction.

Hill (1951) called the Bowen Basin a miogeosyncline but it appears to be an exogeosyncline. Kay (personal communication) agreed with Hill, but the writer thinks that it could be an exogeosyncline or a miogeosyncline depending upon the time when the Bowen Basin began to downwarp. From an overall picture of the events in the Tasman Geosyncline it appears that the Bowen Basin started to downwarp at the beginning of the Permian. Therefore, it seems reasonable, according to Kay's (1951, p. 107) criteria, to classify it as an exogeosyncline, being intracratonic deriving sediments from the Gogango High and the New England Highlands—lands raised in an orthogeosynclinal belt. Moreover, there is no evidence of orthogeosynclinal belts existing in Eastern Australia during the Upper Devonian and later periods which might go to show that Eastern Australia was in the final stages of consolidation as a craton. Voisey (1952) also suggested the Hunter Basin as a miogeosyncline. As stated earlier, its situation between the craton to the west and the New England Highlands to the east suggests similar tectonic conditions to those in the Bowen Basin, and appears to correspond to an exogeosyncline rather than to a miogeosyncline.

The Hunter-Bowen Orogeny

There is some evidence to show that the Hunter-Bowen Orogeny was initiated at the end of the second Permian marine epoch with the formation of anticlines and synclines on the north coast of New South Wales, in the Lower Hunter Valley and also in the extreme east of Queensland. David (1956, I. p. 395) mentioned that it seems likely that a low orogenic barrier or geanticline was upraised along the eastern margin from

Rockhampton to Taree which acted as a definite boundary to the lacustrine region of the Tomago Coal Measures. It may be pointed out here that this geanticline, which has been discussed in the preceding pages, was initiated during the Wallarobba movement and came into existence in New South Wales after the final phase of the Kanimblan Orogeny. In Queensland Hill (1951) showed that the Gogango High was raised during the Tabberabberan Orogeny. There might have been further uplifts along this belt during the initiation of the Hunter-Bowen Orogeny. Moreover, the weight of evidence seems to suggest that the Taree-Bingara region was one of crustal instability after the Lower Carboniferous as shown by the variety of volcanics displayed during Lower and Upper Kuttung times. The down warping of the Hunter-Bowen Exogeosyncline west of this region, and the subsequent Hunter-Bowen thrust along this line seem to confirm the above views. David (1950, I, p. 395) mentioned that in New South Wales, two local depressions came into being on either side of the Lochinyar Dome, wherein the Tomago Coal Measures were deposited, and were partly filled by the material derived from the rising land. The very low elevation of the coal measure swamps and the shallowness of the seas during the Permian are indicated by the intercalations of marine among freshwater beds and *vice versa* in both Queensland and New South Wales.

At the close of the Permian sedimentation the tectonic pressure from the east or a little north of east caused folding and thrusting which diminished from east to west. The thrusting or overthrusting took place along a great arc from Townsville to near New Castle along the Hunter-Bowen line (Carey and Browne, 1938, p. 609). In Queensland, Hill (1951) stated that the western margin of he Gogango High was thrust against the eastern edge of the Bowen Basin, the western edge of the Yarrol Basin against the eastern flank of the Gogango High, and the western edge of the South Coastal High against the eastern boundary of the Yarrol Basin. The climacteric was associated with granitic emplacement and uplift and when it was concluded the entire Queensland section of the Tasman Geosyncline had been established as a errestrial massif and had become an integral part of the craton. The whole of Queensland then behaved as a

craton. Beds in Tasmania and Victoria were not folded by the Hunter-Bowen Orogeny.

In New South Wales, emplacement of granite and injection of serpentine took place in two belts which had been unstable since the Lower Carboniferous Epoch. The Permian beds lying to the west of the Hunter-Bowen line in the Hunter-Bowen Exogeosyncline were only gently folded, while the Yarrol, Esk and Maryborough Epieugeosynclinal sediments were affected strongly, being uplifted, broken by high angled thrusts into horsts and grabens, greatly indurated and sometimes granitised and intruded (White-house 1952). This diastrophism terminated the long eventful history of the major geosynclinal belts in Eastern Australia.

Some Aspects of the Tasman Geosyncline

David (1950, I) conveyed the impression that the Tasman Geosyncline was initiated early in the Cambrian. As was pointed out earlier, there is evidence to show that during the Upper Proterozoic, eugeosynclinal conditions existed on the east side of the Adelaide Miogeosyncline and that both the Fleurieu Eugeosyncline and the Adelaide Miogeosyncline formed the orthogeosynclinal belt with a craton lying to the west. However, if Sprigg's view is correct, it is not improbable that eugeosynclinal conditions existed east of the Adelaide Miogeosyncline. It has been taken for granted by previous workers that the Tasman Geosyncline was initiated in the Cambrian because no rocks older than the Cambrian have yet been found in Victoria, New South Wales and Eastern Queensland in the Fleurieu Eugeosyncline. Kay (1951, p. 91) pointed out "It is believed that the orthogeosynclinal belts were dominated by subsidence of their Protozoic basement. If they had lands with great areas of Protozoic Rocks, these should appear unconformably below younger systems and be exposed in large areas, but there are very limited areas of undoubted Protozoic in the eugeosynclinal belts". It is therefore suggested that the absence of large areas of Proterozoic rocks in Eastern Australia need not be the criterion for fixing the age of initiation of the Tasman Geosyncline.

It has been shown in the past that the Tasman Geosyncline was one huge structure with lands raised within it. It has been

shown that different kinds of geosynclines existed in the different periods and with the meagre data at present available, and applying broad generalization to criteria, it is possible to distinguish them according to Kay's (1951) tectonic types. There are many geologists who hold that some of the geosynclines of Kay (1951) should not be regarded as such. The purpose of this paper is to investigate the validity of his classification with regard to the Tasman Geosyncline.

During the Upper Proterozoic and Cambrian Periods, miogeosynclinal and eugeosynclinal conditions existed in South Australia, and during the Cambrian, evidence is available to show that eugeosynclinal conditions existed in Tasmania, Victoria, New South Wales and Queensland. After the Tyennan Orogeny, the orthogeosynclinal belt moved eastwards and again after the Tabberabberan there was more eastward shifting. It is questionable if a miogeosyncline can exist independently without an eugeosynclinal belt to follow, for both these comprise the orthogeosynclinal belt. For instance, east of the Lambian Miogeosyncline is the Yarrol Epieugeosyncline in the upper Devonian. During the Tabberabberan Orogeny, serpentinous intrusions are indicated in the southern tip of the Anakie High (Hill 1951). The Jack Basin during the Lower Carboniferous has been classified as a miogeosyncline on the grounds that is represented the closing stages of previous miogeosynclinal conditions and also because it did not overlie an eugeosyncline. Serpentinous intrusions are not confined to eugeosynclinal belts and this problem is discussed later. During the Upper Carboniferous, west of the New England Highlands deposition appears to have taken place in intramontane troughs. It is difficult to apply Kay's (1951) classification to these troughs. The writer considers that it indicates the initiation of the Hunter-Bowen Geosyncline of the Permian. Though there is difference of opinion between Kay and the writer regarding the classification of the Hunter-Bowen Geosyncline, the classification into one or the other type of geosyncline hinges on the assumed point of time when this geosyncline began to downwarp. The Hunter-Bowen Orogeny did not terminate the Tasman Geosyncline, as assumed in the past, but the whole of the Tasman Geosyncline appears to have been comparatively stable with development

possibly of taphrogeosynclines and intracratonic geosynclines (Kay 1951) in continental development. Kay (personal communication) stated "There is reasonable doubt that the North American rather simple arrangement will apply universally; hence the need is for caution in applying terms of the classification". The writer had much difficulty while attempting to classify the Tasman Geosyncline according to Kay (1951) for some minor details did not fit into his classification. If his classification is taken on very broad lines with allowances for minor variations, it can reasonably be applied. Each geosyncline has its own individual history and classifications can only be made as generalizations. The writer is fully aware that in certain places (*e.g.*, the Yarrol Epieugeosyncline), interpretation according to Kay's (1951) classification has been difficult because of insufficient data and incorrect correlations in Australia.

The eugeosynclines and miogeosynclines of Eastern Australia correspond fairly well with those interpreted by Kay (1951) in North America. The miogeosynclines of Eastern Australia contain moderate amounts of volcanics. The writer was puzzled many times whether to include these areas in eugeosynclines or miogeosynclines. Kay (personal communication) stated "The term eugeosyncline is applied to a belt in which volcanism occurred at intervals; I would not call the non-volcanic times within this long span 'miogeosynclinal', but rather simply say that the sequence of the period is not volcanic, though in the eugeosynclinal belt, that is the belt in which there is volcanism from time to time". In the Molong and Lambian Miogeosynclines there is evidence of volcanism from Silurian to Devonian times, but at the same time there is abundant development of coralline limestones. It cannot be interpreted as an eugeosyncline because of coralline growths and the argument against its being called a miogeosyncline is one of volcanism. Therefore, the explanation was offered that volcanism may have occurred along tectonic welts, or geanticlinal uplifts giving apparent volcanic sections in miogeosynclines. However, the writer feels that crustal instability, whether in a geosyncline or a craton, may manifest itself by volcanism.

The serpentinous intrusions of Eastern Australia occur in eugeosynclines, miogeosynclines, epieugeosynclines, and along

the margin of an exogeosyncline, those in Tasmania and along the Gogango and South Coastal Highs in Queensland being in eugeosynclines. However, in the Molong Miogeosyncline, a belt of serpentinous intrusions occurs near Wallenbeen, Gundagai and Young along a geanticline which formed during the Bowning Orogeny. In Queensland during the Tabberabberan, serpentinous intrusions are recorded in the Anakie High (Hill 1951). Another occurrence is at Fiefield in New South Wales, which was then probably east of the axis of the Mitta-Mitta Geanticline. In New South Wales one belt of serpentines was intruded during the Hunter-Bowen Orogeny on the eastern margin of the Hunter-Bowen Exogeosyncline, while another belt occurs in the Esk Epieugeosyncline along the eastern margin of the New England Highlands. According to Kay (1951, p. 77) an epieugeosyncline should overlie an 'earlier tectogene'. The Yarrol and Esk Basins have been interpreted as epieugeosynclines overlying earlier serpentinous intrusions in Queensland but. in New South Wales, the serpentinous intrusions in the Esk Epieugeosyncline are considered to be epi-Permian (David 1950. I. p. 392). Therefore, the Esk Epieugeosyncline not only lay over an earlier serpentinous intrusion but also had a later intrusion during the Hunter-Bowen Orogeny. It is pointed out that serpentinous intrusions are not necessarily confined to eugeosynclinal belts or restricted to " the first great deformation when the tectogene was formed " as postulated by Hess, but appear to occur along major zones of weakness. Kay (personal communication) stated that so far as he is aware the long serpentinous intrusive belts in the United States are wholly within the eugeosynclinal belts although isolated ultrabasic intrusions are widely scattered, some far within the craton. Mitchell (1952, p. 125) stated "The author would not agree with H. H. Hess' argument that (1) periodotites are intruded only during the first great deformation process...". Kay (1951, p. 76) pointed out " it is interesting, if not significant, that the ultrabasic belts are successively younger outward in several regions (Hess 1939 ; 1948). Similarly, the Mesozoic belt in the Fraser belt is near the present coast, whereas the Palaeozoic belts seem to be further in toward the hederocraton ". In Eastern Australia, the ultrabasic belts of the Tyennan, Benambran and Bowning Orogenies are farther in toward the craton while those of the Tabberabberan and Hunter-Bowen Orogenies

are near the present coastline. Therefore, the ultrabasic belts seem to be successively younger outward from the craton. Granitization has been said to be restricted to the eugeosynclinal belts (Misch, 1949). Kay (1951, p. 99) stated "the miogeosynclinal belts and the hederocraton are only relatively less invaded by plutonic intrusions than the eugeosynclinal belts; they are not wholly 'amagmatic'". In the East Australian geosynclines synchronous and subsequent batholiths appear to have been emplaced to a greater extent in the miogeosynclines and epieugeosynclines than in the eugeosynclines.

It has been suggested by various writers that an imaginary continent called "Tasmantis" existed east of the present shore line of Australia. Sussmilch (1935, p. 115) who suggested the name stated "the deposition of coarse sediments (grits and conglomerates) at intervals throughout the whole period indicates that the Tasman Geosyncline was bounded for the most part by relatively high land and was probably undergoing elevation simultaneously with subsidence of the geosyncline. The occurrence of coarse sediments along its eastern margin indicates that there must have been an extensive land area lying along its eastern side". It is not proposed to discuss this aspect in great detail as this would be outside the scope of this study but it is suggested that alternatives are also possible. This has a bearing on the evolution of Eastern Australia and is therefore significant. In America, the palaeogeography of the continental borders has been the subject of many hypotheses. Dana a century ago, propounded the hypothesis of "marginal reefs" and later on the theory of "Archean Protaxes". The theory of borderlands was developed principally by Schucherr and Cascadia and Appalachia were shown on either side of the North American Continent as great land areas. The theory of marginal volcanic geosynclines and island arcs has been developed during the past decade. Kay (1951, p. 29) considered "regions beyond the miogeosynclines to have had deep-sinking belts of sediments and marine volcanic rocks—eugeosynclines—with smaller areas in volcanics and linear tectonic welts rising within them". In this paper the presence of eugeosynclinal conditions on the eastern side of Australia from Upper Pre-Cambrian to Lower and Middle Devonian has been demonstrated. Kay (1951, pp. 71, 72) pointed out "the great volume of terriginous sediments

in the eugeosynclinal belts requires source lands, both volcanic, built by accumulation, and tectonic of rocks elevated by warping, folding and faulting. Rocks indigenous to the belts are preponderant. Lavas and coarser volcanic fragmentals remain at or near their original sites; tuffs can have been carried further. In an area subsiding for a long time, volcanic islands resulted when volcanic accumulations were built more rapidly than sinking could accommodate them . . . There were also tectonic lands raised with accompanying plutonism as welts in previously sinking areas, the elevation not exceeding the preceding subsidence; their detritus was essentially of material indigenous to eugeosynclines. The form and distribution of lands in successive times is rarely determinable for more than limited areas. Exposures of rocks of any age and distributions of unconformities are limited and there is little information bearing *on the directions of source of detritus*". It is therefore considered that the sediments in eugeosynclines in Eastern Australia were also indigenous, derived from volcanic islands and tectonic lands. It was pointed out before that batholithic emplacements in the eugeosynclines of Eastern Australia were of minor importance. Perhaps those emplaced earlier in eugeosynclines might have been stripped off and/or buried by later sediments so that only a few traces are left. It has been shown that after the Tabberabberan Orogeny, the geanticlines or tectonic lands formed in Queensland in a former eugeosynclinal belt and their later developments in New South Wales contributed sediments both from east and west. It was even suggested that the Maryborough Basin might be an epieugeosyncline bounded to the east by a tectonic land similar to the Gogango and South Coastal Highs. Under the circumstances, it would appear that the need of an hypothetical "Tasmantis" to supply sediments does not arise and "the occurrence of coarse sediments along the eastern side" need not indicate derivation from a large continent as postulated by Sussmilch, but could be from linear tectonic lands raised in eugeosynclines.

Considering the different orogenic epochs and source areas of sediments in the exogeosynclines and the miogeosynclines, it would appear that, in exogeosynclinal areas, sediments were mostly derived from lands raised in a previous orthogeosynclinal belt. So far as miogeosynclines are concerned, their sediments

would be derived from lands raised within orthogeosynclinal belts. It may therefore be stated that the sediments were of indigenous origin in East Australian geosynclines.

CONCLUSIONS

From the study of the Tasman Geosyncline, the following conclusions can be drawn:

1. Each geosyncline has its own individual history and that classification according to Kay (1951) can only be applied in a general manner to the Tasman Geosyncline.
2. The absence of large areas of Proterozoic rocks in Eastern Australia should not be the criterion for fixing the age of the initiation of the Tasman Geosyncline.
3. The miogeosynclines of Eastern Australia contained more volcanics than those of North America.
4. In the Upper Devonian and Lower Carboniferous epochs, miogeosynclines appear to have existed without an eugeosynclinal belt to follow.
5. The éugeosynclines, miogeosynclines and epieugeosynclines correspond fairly well with those in North America in their development.
6. Serpentinous intrusions are not confined to eugeosynclinal belts, nor do they appear to be related to the first great deformation of the crust as postulated by Hess, but occur along major zones of weakness in eugeosynclines, miogeosynclines, epieugeosynclines, and edge of an exogeosyncline in Eastern Australia.
7. In Eastern Australia, ultrabasic belts of the Tyennan Benambran and Bowning Orogenies are further in toward the craton while those of the Tabberabberan and Hunter-Bowen Orogenies are near the present coastline. Therefore, the ultrabasic belts seem to be successively younger outward from the craton, as has been observed in North America (Kay 1951, p. 76).
8. In the Tasman Geosyncline granitization is not confined to eugeosynclinal belts as suggested by Misch (1949).

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9. The need for a hypothetical "Tasmantis" to supply sediments from the east to the Tasman Geosyncline does not appear to be necessary, but could be from linear tectonic lands raised in eugeosynclines like the Gogango and South Coastal Highs in Queensland.
10. The source of sediments in Eastern Australia in Eugeosynclines appears to be from tectonic welts within them, and lands raised in the eugeosynclinal belts yielded sediments to adjoining miogeosynclines; with deformation of the latter, detritus spread to later order geosynclines like the exogeosyncline. Sediments in the Tasman Geosyncline appear therefore to be indigenous as was pointed out by Kay (1951) with regard to the North American Geosynclines.
11. In the Tasman Geosyncline too, as in North America, stratigraphic evidence supports the hypothesis that continents have grown through intermittent dynamic processes by reduction of oceanic areas through an intermediate "island arc" stage.

It is obvious that much field work requires to be done in Australia to correlate accurately the data on stratigraphy in order to prove the validity of the generalisation made in this paper. Until then the suggestions and conclusions drawn from this study are only tentative. The author is fully aware that some of his interpretations may be wrong, but every attempt has been made, but not always successfully, to reconcile the various views of geologists in Australia on stratigraphy and orogenesis. The generalisations given in the discussions have been suggested with the knowledge that they are based on incomplete data. But it is hoped that they will stimulate further work and contribute to a satisfactory picture of the stratigraphic and tectonic history.

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SILLIMANITE-KYANITE ASSOCIATION NEAR JAMORI, SIDHI DISTRICT, VINDHYA PRADESH. BY M. V. N. MURTHY, B.SC. (HONS.) (MYSORE), A.I.I.SC., PH.D. (GLAS.), *Geologist, Geological Survey of India.* (With Plate 18.)

ABSTRACT

West of Sidhi, near Jamori, in Vindhya Pradesh, a narrow zone of muscovite-chlorite schists, show bluish-green 'knots' (composed of sericite) and occasional massive seggregates (composed of sillimanite and kyanite or kyanite only). The two alumino-silicates which should not co-exist according to the phase rule, lie comfortably side by side even in the same thin sections and are not derived from (i) each other (by inversion or replacement) or (ii) from biotite as noted by Roy in Darjeeling District. The low grade schists were originally sillimanite-bearing biotite-schists. Metamorphic differentiation, presumably gave rise to the seggregations; under such physico-chemical conditions, both sillimanite and Kyanite can probably crystallize together. The low grade schists result from retrograde metamorphism which converted sillimanite into (?) sericite and biotite into chlorite.

INTRODUCTION

During the last week of April, 1951, the writer made a brief study of a small area near Jamori village (24° 25′: 82° 54′), about 2¼ miles west of Sidhi (24° 25′: 82° 55′), while investigating the occurrence of gallium-vanadium-bearing minerals reported by Sri R. D. Bhatnagar, Consulting Mining Engineer and Geophysicist, to occur as 'lumps' of a greenish mineral. After a brief preliminary examination of the locality, a rapid prismatic survey of the occurrence, on a scale of 1″=50 yards, was made and areas where the bluish-green lumps occurred conspicuously on the surface, were roughly demarcated. Five grab samples were collected which were analysed qualitatively for gallium and vanadium by the National Physical Laboratory, Delhi, which confirmed the presence of these elements in the samples sent.

In micro-sections, the 'lumps' essentially consist of (?) sericite. Occasionally, however, unaltered sillimanite and kyanite are recognisable. The presence of these minerals, considered to be indices of high grade regional metamorphism of pelitic rocks, in low-grade muscovite-chlorite schist is apparently anomalous. Besides, the association of sillimanite and kyanite seen side by side even in the same thin section is rather unusual and has been reported previously in India only from Darjeeling (Roy

1935, 1947). This short paper is based on the brief studies made by the writer during his visit to Sidhi and also from a study of micro-sections.

Location of the occurrence

The mineralized zone is located a furlong east of the junction of the Rewa-Sidhi and Beohari roads. It extends in a roughly NE-SW direction.

Topography

The country near Jamori is gently rolling and several streamlets and gullies drain northwards, ultimately joining the Son which flows in an ENE direction, about three miles north of this village. There is a prominent mound immediately north of the 59th milestone, north of the road.

Geology of the locality

The main rock-types of the locality are schists which include talc-rich types locally varying to soapstones and steatite. Near Jamori, muscovite-chlorite schists are well developed, and are especially well exposed in the mound near the 59th milestone. The schists are interbanded with fine-grained, compact, well jointed, amphibolites ; thin bands of banded magnetite-quartzites are occasionally exposed on the north-eastern slopes of the hill mentioned above.

SW of the 58th mile 7th furlong-stone, the schists strike roughly N-S with dips to the east and west (structural syncline). North-eastwards, the foliation direction is NE-SW and NW of the 50th mile 5th furlong stone the strike is again almost N-S with a dip of 50°-60° to the W.

Extent of the zone.—The whole zone in which the blue green mineral occurs, extends for about a mile in a roughly NE-SW direction. In the south-western extremity (about 100 yards SSE of 58 mile 6th furlong-stone) it is about 30 yards wide and is not seen further west.

Microscopical characters

Chlorite-muscovite-quartz rock.—The country rock is invariably non-schistose but sometimes schistose. It is a greenish rock

with reddish brown knots on the weathered surface and is essentially composed of chlorite, muscovite and quartz. The chlorite is mainly a pale green variety (clinochlore) and slightly pleochroic: X=pale green, Z=colourless. The flakes show low birefringence (almost isotropic) and multiple twinning. All the flakes show inclined extinction with a very small angle. In some of the slices slightly pleochroic chlorite flakes show ultra-blue interference colours (pennine). Chlorite gives the impression that it is derived from original biotite; occasionally some flakes show pleochroism in brown, typical of biotite. In some of the slices chlorite and muscovite are intergrown simulating sub-ophitic texture, which is presumably due to recrystallization. Besides muscovite there are also fine flakes of (?) sericite. In thin section the bluish lumps in the schistose rocks are essentially composed of very fine (?) sericite flakes. One slice of the schist showed a colourless garnet altering into chlorite.

The sections often show needles or/and short stumpy crystals of rutile. In the same section, muscovite and chlorite may or may not show inclusions of rutile needles while occasionally a large irregular patch of rutile with a dark border is seen. Tourmaline is sometimes present as large prisms but usually as short ones.

(b) *Bluish green lumps.*—In thin sections the 'lumps' are conspicuously altered and only rarely are unaltered remains recognisable. In some sections the probable former presence of original cross-fractures, can be identified in what is now an aggregate of (?) sericite and muscovite. A few irregular thin streaks of (?) iron ore are present and also aggregates of diaspore.

(c) *Large massive boulders.*—Two varieties were collected: (i) Bluish-white mass composed of an aggregate of distinct shining prisms; flaky minerals are seen locally. The slices show both large prisms and numerous thin needles of silimanite as also a few prisms of kyanite. Both these minerals alter into flaky (?) sericite. (ii) Bluish-white medium-grained massive boulder consists of haphazardly arranged, small prisms associated with muscovite. The slices show mainly irregular grains of kyanite (occasionally) twinned, altering along the boundaries into (?) sericite. Some of the sections almost wholly consist of fine (?) sericite.

(d) *Massive kyanite.*—The thin sections of the massive kyanite seen in the south-western extremity of the zone show mainly coarse blades of kyanite and some muscovite. Sillimanite is absent.

Geological history

The absence of any quartz-kyanite or quartz-sillimanite pegmatites or veins, the invariably altered nature of the bluish lumps which in all probability were original sillimanite aggregates proves conclusively that the alumino-silicates were not introduced, after the formation of the chlorite-muscovite schist. It is likely that they were formed prior to the alteration processes which led to the development of the low-grade assemblage.

Three alternative modes of origin may be considered: (1) In Bhandara, S. K. Chatterjee (1932, p. 301) suggested that "muscovite-chlorite-schists yielded the rocks bearing kyanite and sillimanite as the result of pneumatolytic metamorphism attendant on the intrusion of tourmaline granite and involving the operation of boric oxides or borate with occasionally vanadium derived from its residual magma liquor". Chatterjee did not find the association of both sillimanite and kyanite in the same rock, but considered dumortierite as an intermediate stage. In the Sidhi rocks, tourmaline occurs only in minor amounts in the schists and is a rare mineral in the quartz veins of the locality. The author is not aware of any tourmaline granites in the vicinity. The band of granite near the Sidhi-Rewa and Sidhi-Beohari road crossing is not tourmaline-bearing. It is, therefore, improbable that boron-bearing solutions could have been responsible for the development of the alumino-silicates. Vanadium has been noted only in spectroscopic amounts and is unlikely to have caused the crystallization of sillimanite and kyanite. (2) In the Williamson district in Australia where kyanite-sillimanite rocks are present, also in low grade schists, Alderman, (1942, 1950) invoked alumina metasomatism. He has noted the formation of kyanite and sillimanite in rocks of varying composition (even dolomite marble and quartzite). The trend of replacement is across the strike of the country rock. He also describes kyanite-quartz veins. etc. As already noted, these features are absent in Sidhi. (3) Sillimanite and kyanite are formed during regional metamorphism of pelitic rocks and

their close association has been often noted (Wycoff, 1952; Roy, 1935, 1947). Recently Hietanen (1954) has noted the close association of andalusite, kyanite and sillimanite in schists.

Although, the writer has not mapped the surrounding areas, from the present studies it would appear that in Sidhi the crystallization of sillimanite can be more satisfactorily explored by regional metamorphism than by the alternative processes suggested by Chatterjee and Alderman.

We have seen that the blue nodules and knots appear to consist essentially of original sillimanite. Sillimanite and kyanite were found together mainly in the larger massive boulders. Study of the thin sections of these does not give the impression that the minerals are derived from each other by inversion or replacement. Although according to the phase rule the two forms of the alumino-silicate should not occur together (Barth. 1952, p. 256) they are often recorded side by side. In Darjeeling (Roy, 1935, p. 32) both sillimanite and kyanite develop from biotite. In Sidhi, however, this does not appear to be the case. Hietanen (1954, p. 332) explains the association of the three alumino-silicates as resulting from crystallization "under physico-chemical conditions in which all three can exist in equilibrium". In Sidhi, sillimanite and kyanite apparently crystalized together in some of the larger lumps which presumably developed by metamorphic differentiation. Such conditions perhaps favour crystallization of both sillimanite and kyanite. It is noteworthy that the massive boulders show little quartz, probably indicating higher temperatures of crystallization in contrast to the quartz-kyanite veins developed by metamorphic differentiation at lower temperatures.

In Sidhi, it would appear that regional metamorphism, when sillimanite and kyanite crystallized in biotite schists, was followed by regressive metamorphism resulting in the recrystallization of the schist, conversion of biotite into chlorite and sillimanite-kyanite into (?) sericate and also crystallization of muscovite presumably from potash released during the formation of chlorite from biotite. It is interesting to note that in Sidhi, sillimanite alters into (?) sericite and not to kaolinite as in Australia. This is probably due to alterations taking place at higher temperatures.

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On the Geology of the Barwaha-Katkut area of the Narbada Valley, Nimar District, Madhya Bharat. By M. K. Roy Chowdhury, M.Sc., *Geologist, Geological Survey of India* and V. V. Sastri, M.Sc., *Assistant Geologist, Geological Survey of India.* (With Plates 19 & 20).

CONTENTS

ABSTRACT

The present work has shown that the so-called " Bijawar slate series " is older than the granitic rocks which are probably consanguine with the Bundelkhand granite gneiss. The evidences collected show that the breccia, which is found as large patches and which was considered to be a part of the Bijawar formation occurs mostly as an intraformational rock, although it probably originated from the subsidence or collapse of the dolomite in the large solution cavities in post-Vindhyan period, followed by the silicification of the fragmentary material. The large exposures of sandstone which were once correlated with the Mahadevas most probably belong to the Lameta horizon. A patch of sandstone at the western side of the area which was previously suspected to be equivalent to the Nimar sandstone, the basal member of the Bagh beds, has now been found to occur as intercalations in the coralline limestone, the uppermost horizon of the series.

INTRODUCTION

The Barwaha-Katkut area, described in the present paper, lies at the western border of sheet 55 B/3 and includes a small portion of the adjoining sheets 55 B/4 and 46 N/SE. The area, comprising of about 100 square miles, is bounded to the north, west and south by the flows of the Deccan Trap lavas while to the east are the Vindhyan rocks. It is the westernmost portion of the large outcrop of the pre-trappean rocks at the eastern side of the Narbada Valley in Madhya Bharat. It forms an elongated strip from a few miles north-west of Barwaha to a few miles north-east of Katkut. Except a small patch at the extreme north-eastern portion the area falls in the present Nimar district. The area east of the Kanar river is included in the Indore district and is a part of what is generally known as "Dhar Forest".

The area was first geologically mapped by W. T. Blanford and A. B. Wynne (*Mem., G.S.I.*, Vol. VI, pt. 3, 1869). It appears that F. R. Mallet also visited the Dhar Forest area but his published account (*Mem., G.S.I.*, Vol. VII, pt. 1, 1869) deals mostly with the Vindhyans. The geological map of P. N. Bose who resurveyed the area (*Mem., G.S.I.*, Vol. XXI, pt. 1, 1884) on better topographical maps does not show much deviation from the map prepared by Blanford, except for a disputable assignment of the Lameta rocks to the Mahadeva group of the Gondwanas. This alteration was based on the information collected by H. B. Medlicott (*Rec. G.S.I.*, Vol. VIII, pt. 3, pp. 72-74, 1885). During the field season 1902-03, E. Vredenburg assisted by L. L. Fermor (General Report of the G.S.I. for 1902-03, pp. 14, 19-21, 1903) carried out a detailed survey of the Nimanpur Pargana (Dhar Forest), including a major portion of the present area. A map published with their summarised account shows considerable modification of the previous work. A more elaborate account and a larger map would have been very helpful at this stage. Fermor in his Memoir on manganese-ore (*Mem., G.S.I.*, Vol. XXXVII, pt. 4, pp. 672-677, 1909) gave more detailed information regarding the manganese-bearing breccia of this area. The senior writer who carried out an investigation of manganese-ore around Barwaha submitted a detailed report on the geology of the area (MSS. Report, 1951-52).

Some fantastic ideas of the geology of the area have been propagated through the unpublished reports of S. M. Baxter,

who, representing an American firm, was engaged in 1947 in the study of regional and economic geology of the previous Holkar State. Baxter considers that no formation in the area is older than Pliocene in age and the sandstones, including the Vindhyans, are of fluvio-glacial origin, later modified by ascending thermal waters. According to him, these thermal waters deposited the limestone deposits of the area. The complete disregard of the geological features of the area shown by Baxter is deplorable.

The writers are grateful to Dr. M. S. Krishnan for going through the manuscript of this paper.

GENERAL GEOLOGY

The following is the provisional classification of the rock types met with in the area:—

Recent	Alluvium, calc-tufa, etc.
Deccan Trap (Malwa Trap) . .	Basalts with trap dykes and inter-trappeans.
------ Unconformity ------	
Lametas	Conglomerate, grit, sandstone and limestone.
Bagh beds	Coralline limestone and sandstone.
------ Unconformity ------	
Post-Vindhyans	Breccia and boulder beds.
------ Unconformity ------	
Vindhyans	Shale, sandstone and quartzite.
------ Unconformity ------	
Archaeans	Granite, pegmatite and hybrids; dykes of gabbroidal rock and felsite-prophyry, phyllites; quartz-sericite- and chlorite-schists; dolomite and calc-schists; quartzite and schistose conglomerate.

Archaeans.—The predominant rock of this group is dolomite. It frequently crops out as inliers in the massive breccia in the main river sections of the area. It varies from pure dolomite to cherty and quartzitic rocks. Next in abundance are phyllites passing into chlorite- and quartz-sericite-schists. Large exposures of these rocks occur at the base of the Vindhyan quartzites near Sortipura and west of Badel. At the former locality the rocks pass northward into a schistose conglomerate with elongated pebbles, mostly of rhyolite, lying along the schistosity planes.

In the northern portion of the area mapped and in the *nala* sections north and south of Kanar, massive porphyritic granite crops out intruding into the phyllites and schists. As a result of this injection, hybrid gneisses have been produced.

Vindhyans.—The Vindhyans which crop out extensively in the eastern side of the area consist of shales, gritty sandstone and quartzite. On the northern side these are occasionally faulted against the breccia.

Post-Vindhyans.—The breccia, cherty and calcareous and occasionally conglomeratic, attracted the attention of the earlier workers in this area. This forms wide exposures, particularly along the existing river channels. The evidences collected during the present work support the view of the senior writer that it mostly occurs as an intraformational rock with an uncertain stratigraphical position between the Vindhyans and the Lametas. The Lametas rest on this rock and occasionally boulders of the Vindhyan rocks are found embedded in it. Although at a few places it is thrown against the dolomite and quartzite, closer examination, however, reveals this feature to be due to faulting which is subsequent to the formation of the breccia, rather than the breccia being the result of faulting.

There are a few exposures of boulder beds which are peculiarly confined to the banks of the Choral river. The occurrences are of lenticular nature of varying thickness up to a maximum of about 35 feet. These consist of boulders of Vindhyan quartzite and breccia. At places all the boulders are of Vindhyan quartzite. Although the boulder beds occupy the same stratigraphical position as the basal conglomerate of the Lameta formation, these are distinguished by their massive character, peculiar mode of occurrence and the presence of bigger boulders.

Bagh beds.—There are a few small detached outcrops of fossiliferous Cretaceous limestone (coralline limestone) at the western side of the area. The main exposures are near Agarwara in the *nala* section between Yelam and Pirakalan and at the base of the sandstone scarp south of Ghatia. Bose included the exposures of the sandstone near Yelam in the Nimar sandstone, the basal member of the Bagh beds. But it has been found that this sandstone, fine-grained, white and mottled, actually occurs as lenses in the coralline limestone which occupies the topmost

horizon of the Bagh beds. The limestone at the base of the Ghatia scarp most probably underlies the sandstone as there is no sufficiently strong evidence to support Medlicott and Bose, who concluded that the limestone rests on the denuded surface of the sandstone.

Lametas.—Grit and sandstone, occasionally felspathic and frequently conglomeratic, form mounds and low ridges on the breccia in the neighbourhood of Barwaha. Around Katkut these rocks occupy a fairly extensive area and vary in thickness from a few feet to more than a hundred feet. In the latter area, the basal portion of the formation passes, at places, laterally to an arenaceous limestone. Blanford and Bose correlated these rocks with the Mahadevas but the present writers corroborate the views expressed by Vredenburg and Fermor that these belong to the Lameta horizon.

Deccan Trap.—Deccan Trap lava flows, up to the boundary of which the mapping was extended, form the high plateau of Malwa to the north. These are found at several places in the area mapped as detached cappings on all the rock types mentioned before. Due to extreme irregular configuration of the pre-trap country these rocks are found to be perched at all elevations, even at the base of the high ridges of the Vindhyan and the Lameta formations. At a few places trap dykes have been found to be cutting through the pre-trap formations. Exposures of fossiliferous inter-trappean limestone were noticed near Yelam and Rupabardi.

Recent.—Recent formations consist of alluvium, boulder beds and calc-tufa. Except at a few places the alluvium is a thin residual layer of clays. A bed of recent conglomerate near Yelam, previously included in the Nimar sandstone consists mostly of trap boulders in a calcareous matrix. A fairly large deposit of calc-tufa occurs in the Kanar river section near its confluence with the Satbhairon *nala.*

DETAILED DESCRIPTIONS

Archaeans

Although mention was made of the schists and gneisses exposed in the area no attempt was made by the previous workers to delineate them in their maps. Blanford described these rocks

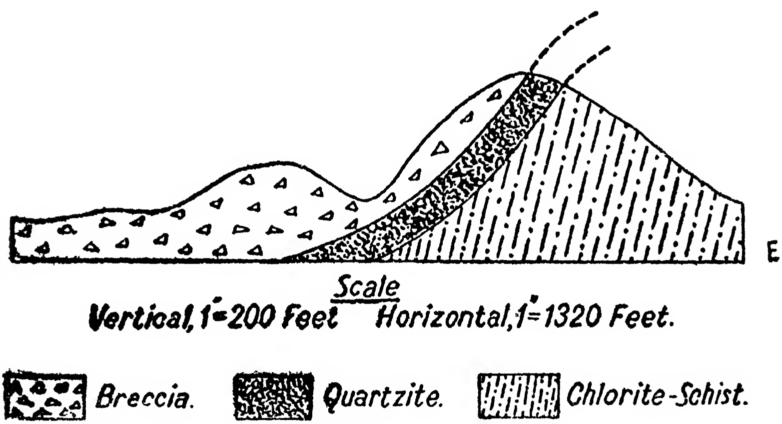
under "Metamorphic series" and "Bijawar series". According to him the former consists of "granitoid and gneissoid" rocks which include granite, syenite, gneiss, hornblende schist, quartzite and other crystalline formations. He included other rocks like laminated limestone, breccia, quartzites, clay slates, etc., in his Bijawar series, based on the observation made by Mallet, who from his experience, had ascertained that these rocks are equivalent to the Bijawars of the type area. His examination of the crystalline rocks being a cursory one, he was not very definite about the actual relationship of the two series. He wrote (*Op. cit.*, p. 39) "Although by no means clearly made out the impression produced by the rather rapid survey which was made of the country was that the two passed into each other in all probability". Bose in his later work retained the above classification of Blanford, placing the limestone and the breccia in the Bijawars and the phyllites, schists and the gneissic rocks of the area in the Metamorphics. According to the present writers the limestone or dolomite occurs interbanded with the other schistose rocks of the area. These were later injected by the granite, forming hybrid gneisses.

As the archaean rocks of this area are covered by various later formations, the exposures are comparatively rare and widely separated. Dolomite, the predominant rock of this formation, is mostly exposed in the beds of the main rivers of the area, *viz.*, Odhali, Choral and Kanar. Phyllites and schists are mostly exposed near Sortipura, about three miles east of Barwaha and near Badel.

Phyllites and Schists.

The widest exposure of phyllites and schists occurs in the depression at the head of the tributary *nala* near Sortipura. The rocks consist mainly of phyllites passing into a quartz-sericite schist and chlorite-schist with subordinate bands of quartzite, dolomite and schistose conglomerate. These are overlain by Vindhyan quartzite to the east and thick beds of breccia to the west. The eastern boundary is marked by a straight scarp whereas the boundary at the western side is irregular due to numerous deep notches at the head of the *nalas*.

The junction of the chlorite-schist with the breccia near the river was considered by Blanford to be a faulted boundary. He wrote (*Op. cit.*, p. 101) "The metamorphics in the Nerbudda are faulted against the Bijawars ; hornblende schists belonging to the former, coming against breccia, dipping at 50° to the south-west belonging to the latter. The hornblende schists are striking east-10°-north, vertical". The junction here is marked by a fairly persistent band of quartzite. The quartzite is of a flaggy type and does not show any sign of brecciation. The presence of this undisturbed quartzite at a faulted boundary is difficult to conceive, and furthermore the chlorite-schists east of the band of this quartzite, although much contorted at places, show the same general strike (N.N.W.-S.S.E.) and dip (40° to 70° S.S.W.). Most probably the breccia was accumulated on a structural depression as shown in the following sketch:



The breccia near its contact with the quartzite appears to be more compact and crystalline than the usual type. This may be due to the effect of the superincumbent load or of later crustal movements in the area. In the north it definitely rests on the phyllites and schists forming a zigzag boundary due to later erosion.

Across the river and south of the above exposure Bose (*Op. cit.*, p. 13) noted that the Bijawars, represented by limestone, rest unconformably on the schists, instead of being faulted against them as conceived by Blanford.

The chlorite-schist is mostly exposed south of the forest road which runs from Sortipura towards Nilgarh and at the base of the high ridge ·990, about a mile north-east of Sortipura. The rock is either highly schistose or somewhat massive; the latter occurring as thin bands in the former. Bands of slaty phyllite are occasionally observed in the chlorite-schist south of the forest road mentioned above. The common constituents of the rock are chlorite, calcite, quartz and plagioclase. Sericite and muscovite are occasionally seen. A vein of acicular aggregate of tourmaline needles runs across a specimen from the southern portion of the exposure. The chlorite-schist exposed at the base of the hillock ·990 passes northward to a fairly thick band of schistose conglomerate. The pebbles, up to two inches in length, are drawn out along the planes of schistosity of the rock. The pebbles are mostly of a rhyolitic rock and occasionally made of cherty and quartzose material. Under the microscope, the rhyolite pebbles show elongated laths of plagioclase in a fine-grained groundmass of quartz, calcite, chlorite, leucoxene and suspected glass. Sometimes the felspar laths are grouped or clustered together. The pebbles are also much sheared with veins of calcite and chlorite penetrating the sheared planes. Occasionally, vesicles filled with calcite, chlorite, quartz and iron oxide are present in the pebbles. The matrix is mainly chlorite with variable amounts of calcite. The veinlets of calcite in the pebbles and also in the matrix suggest that this material was introduced at a later stage. The calcareous material is also very common in the more granulitic rock south of the above band. A thin section of this rock consists of fairly large crystals of plagioclase, chlorite and calcite in a fine groundmass of quartz and sericite.

The quartz-sericite-schist occupies a fairly large area between the above exposures of chlorite-schist and also crops out at the head of the *nala*, north of the band of schistose conglomerate. The latter outcrop is frequently concealed by the debris of the Vindhyan quartzite and the breccia which forms the ridges to the east and west respectively. The rock is mostly a very fine-grained slaty phyllite with a typical phyllitic sheen and often with a soapy touch. The phyllitic rocks pass into schistose types. At the southern side the rock dips vertically or to the south along with the associated chlorite-schist. Northward it assumes a steep northerly dip of 60° to 70°, the strike varying

from E.-W. to E.N.E.-W.S.W. Under the microscope, the rock is made of extremely fine-grained quartz with minute specks of sericite. Veins of quartz and calcite are present.

In the *nala* sections, north of the forest road to Nilgarh there are a few bands of dolomite, quartzite and chlorite-schist in the phyllite. Immediately north of the band of chlorite-schist there is another thin band of altered coarse gabbroidal rock. This is aligned along the schistosity of the associated quartz-sericite rock. Under the microscope, the rock is composed of laths of saussuritised plagioclase felspar in a groundmass of chlorite and serpentine with a little secondary quartz. The chlorite appears to have been formed from pyroxene, the relict outline of which is occasionally seen.

About half a mile north-west of the above bands there are exposures of a massive quartzose rock which form low mounds by the side of a feeder *nala*. The rock contains numerous phenocrysts of quartz and felspar in a fine-to medium-grained groundmass. The removal of these crystals due to weathering often gives a pitted appearance to the rock. Under the microscope, the rock shows phenocrysts of euhedral quartz and felspar in a groundmass consisting of quartz, felspar, chlorite and iron oxide with occasional presence of sericite and calcite. The quartz phenocrysts occasionally show hexagonal outline and the felspars are generally much altered. In a section of the coarse-grained rock large number of grains of flourite were noticed. These are not detectable in the hand specimen.

In the bed of the Choral river section west of the above exposures there are a few detached outcrops of quartzite, hornblende schist and dolomite. The Choral river cuts its course through a very thick bed of breccia at this place and the above rocks crop out as inliers. The most interesting exposure of this section is a thin band of phyllite which marks the southern boundary of a faulted block of Lameta sandstone, about half a mile north-east of the temple of Jayanti Mata. The phyllite, similar to the rock described before, passes southward to a pebbly phyllitic rock, the pebbles of which are flattened and elongated and are of the same cherty breccia which forms a thick bed to the south. This is most probably due to a subsidiary fault between the phyllite and breccia, originated at the influence of the major

fault which has affected the sandstone to the north. As a result of this fault, pebbles of the breccia have been incorporated in the phyllite.

About half a mile north of Sadkhera and in the bed of the Choral river there is another small exposure of phyllite occurring between the bands of dolomite and quartzite. The junction of dolomite with the phyllite is gradual and the transitional rock may be called a schistose dolomite. It contains abundant sericite. This gradual passage is more marked in a much wider exposure of these rocks in the river bed further north near Ramkola. At the southern side of that exposure dolomite passes into a calc-schist with the development of schistosity and presence of sericite. The associated rock is mostly a dark, fine-grained phyllite consisting mainly of quartz, sericite and chlorite. Biotite, muscovite and limonite are also present. Other accessories are tourmaline, epidote, apatite, etc. A few large grains of quartz may be relict porphyroblasts. This phyllite and the associated limestone show the same regional dip, *i.e.*, to the north but the rocks near Sadkhera dip to the W.S.W.

The next occurrence of schistose rocks to the north is observed east of the village of Barjhar. Here again a thickly bedded schistose dolomite, dipping to the N.N.E. (45°), passes into quartzite. Associated with these rocks there is a thin band of much altered micaceous rock which, under the microscope, consists of needle-shaped laths of biotite and altered felspar arranged irregularly in a groundmass of quartz, muscovite and calcite. This rock may be related to a lamprophyre.

The exposures of the phyllites and schists are rare at the western side of the area mapped. There is, however, a fairly large exposure of these rocks in the Katgi *nala*, west of Badel. The rocks are mostly buff and light grey phyllites with veins of quartz. Near Nagjhiri the phyllite passes into a dark chlorite-schist with occasional presence of hornblende schist, actinolite-schist and limestone. A band of massive quartz is exposed at the base of the Vindhyan scarp south of the *nala*. This appears to be connected with the wider exposure of a similar quartzite at the eastern side of the narrow ridge, north of Nagjhiri. At the former place the junction of this rock with the overlying Vindhyan quartzite is obscured by the debris but at the latter place it appears to be interbanded with the steeply dipping phyllite and

occurs at the base of the horizontally bedded Vindhyan quartzite. The strike of the phyllites and schists in this area varies between E.S.E.-W.N.W. and E.N.E.-W.S.W. The dip is mostly to the north but vertical or steep dip to the south is not uncommon.

Dolomite

This rock generally forms fairly wide exposures and crops out frequently in the main drainage channels of the area. On the authority of Mallet, Blanford included this rock in the Bijawars along with the breccia with which it is frequently associated. Bose, and even the later workers in the area like Vredenburg and Fermor maintained that this rock constitutes an important member of the Bijawars which occupy a considerable area of the Dhar Forest.

Blanford regarded the siliceous limestone to be of later formation than the gneissic rocks due to his interpretation that the laminations in the rock, marked by the siliceous bands, correspond to the cleavage planes and not with the original planes of stratification. This conclusion was based on the remarkable consistency of strike and dip of the foliation which according to him, are characteristic properties of cleavage. Bose did not fully agree with him and he wrote (*Op. cit.*, p. 12). "If the bands cannot be trusted to represent bedding, it is equally doubtful if they 'generally correspond to original cleavage planes', as they have been considered to do by Mr. Blanford; for the dips of the laminae were found to be neither so generally high, nor, if high, so very steady as would justify such a conclusion". According to the present writers the laminations of the dolomite are conformable with the foliation of the gneissic rocks and schists. If the laminations of dolomite represent cleavage then probably the same deformative forces gave rise to foliation of the schists and the gneisses and all these rocks may be treated in the same group.

The principal exposures of dolomite are in the sections of the Odhali *nala*, north of Barwaha, Choral river, near Barjhar and the Kanar river, north-east of Katkut. The exposure of dolomite in the Odhali *nala*, and its smaller outcrops in the Choral river to the east and near Nandia to the west dip to the W.S.W., markedly different from the general northerly dip of this and the associated rocks of this area. This change of strike may be

due to a concealed fault or may be due to local flexure with a sharp change of strike of the beds. Near Barjhar the dolomite occurs as inliers in the thick overlying beds of the Vindhyan quartzite, breccia and the trap. The rock, dipping 40° to 45°, is mostly exposed in the river bed; the mounds and ridges on both sides being formed of the overlying rocks. The Kanar river, north-east of Katkut, flows through a deep channel cutting through large exposures of dolomite and breccia. Both the rock types are concealed by the Lameta sandstone within a very short distance west of the river bed. Although the junctions of the dolomite and the breccia are sharp in this area there are no signs of disturbance near the contacts. Near Ratagarh the senior writer during his previous visit noticed that the breccia occupies depressions which are of the nature of pot-holes in the dolomite. These are probably the remnants of the original thick capping of breccia which has subsequently been eroded away. The southern side of the small inlier of dolomite east of the deserted village Kanksiakhera shows a sharp junction with the breccia. The line of junction corresponds with the strike of the dolomite. The rocks show smooth slickensided surfaces at the contact suggesting abrasion due to a slip along the dip of the dolomite. As no brecciation of the dolomite is noticed the breccia was probably dragged along the dip slope of the dolomite on which it rested.

The dolomite is usually laminated due to the presence of thin bands of chert or quartz. At places the ramifying veinlets of silica are very irregularly distributed in the massive dolomite, thus producing ribbed or pitted weathered surface. Bose (*Op. cit.*, pp. 11-12) noted that the siliceous bands increase in thickness towards the surface and masses of this segregated material are occasionally associated with the dolomite. The present writers also observed that exposures of these rocks in the bed of the rivers are almost free from this material whereas the rock exposed on the higher grounds an occasionally highly impregnated with the siliceous material. Sometimes the rock cropping out in the bed of Choral river south-east of Ghatia, is so siliceous that it is almost a quartzite. Large exposures of this rock almost free from the siliceous laminations are also common, *e.g.*, in the Odhali *nala* section north of Barwaha. According to S. M. Baxter (MSS. Reports), who conducted the preparation of a large scale

plan, the dolomite in the above section is visible over an area of more than 600 acres. The purer bands of dolomite are being used for local lime burning. The rock varies from light grey to pink in colour.

Granite

Granite is exposed only in the stream sections at the extreme northern portion of the area mapped in the neighbourhood of Kanar. This is probably the continuation of the granitic rocks reported earlier near Mirzapur. In the bed of the Kanar river west of Kanar, a fairly thick band of pegmatitic granite has intruded the phyllites giving rise to a hybrid gneiss. The pegmatite is frequently altered to a gritty kaolin. The phyllitic bands are less altered. North of the hybridised rock, unaffected phyllitic rocks are exposed at the bend of the river, south-east of Okhla.

In the *nala* section east of Kanar a massive granite is exposed immediately north of the road leading to Pandutalao. The granite gradually passes into a dark hornblendic rock which could be followed upstream for a distance of more than half a mile along the course of the *nala*. This rock occasionally develops schistosity and is often permeated by ramifying veins of pegmatite. This is followed by occasional exposures of light-coloured granite at the base of the thin beds of grit and conglomerate of the Lameta formation. The surrounding country is covered by the trap or mantles of black soil. The granite is essentially composed of quartz, felspars (orthoclase, microcline and plagioclase), chlorite and biotite. The felspars are frequently saussuritised giving rise to epidote, sericite, calcite, etc. The accessories are muscovite, epidote, apatite, iron-ore, etc. Tremolite is a common constituent of the dark rock. It is frequently replaced by green biotite. Sometimes chlorite predominates and appears to have been formed after olivine. The dark rock is probably an inclusion of a basic rock in the granite.

According to Blanford (*Op. cit.*, p. 98) the granite near Mirzapur is abruptly succeeded by limestone. This led him to doubt about the intrusive character of this granite but he was not very sure whether the limestone rests upon it naturally, or " whether the two rocks are separated by a fault ". In the present section also the junction between the dolomite and the granite is not clear but the granite has definitely intruded the phyllites, which

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in clear sections elsewhere are found to be interbanded with the dolomite.

Vindhyans

As the present mapping was extended only up to the boundary of the Vindhyans, the examination of this formation was of cursory nature and was confined to the marginal areas only. Fairly detailed knowledge regarding this formation is to be had from the works of the previous observers. Mallet who is credited with extensive knowledge of the Vindhyans of this area considered that the rocks belonging to this formation probably represent the Rewa and Bhander divisions. According to Bose the basal thick-bedded sandstone probably belongs to the Kaimur series. In the map produced by Vredenburg and Fermor large portions of the Vindhyan rocks, including those of the present area, have been indicated as Lower Vindhyans. They separated the Upper Vindhyan rocks into the Kaimur and the Rewa series. The reason for this modification has not been mentioned in their report.

The Vindhyan rocks of the area extend to the east as a " low, wild, jungle-clad plateau ". The western boundary of the Vindhyan country runs more or less in a straight line for a distance of about 12 miles from the bed of the Narbada river, about two miles east of Sortipura to Kundia where rocks are completely covered by the Deccan Trap lava flows.

The northern boundary, as long as the rocks are capped by the trap, is irregular but westward in the vicinity of Badel the boundary against the Lametas and the breccia runs more or less in a straight line. The straightness of the western boundary drew the attention of Bose who wrote (*Op. cit.*, p. 15) " the Vindhyans run parallel to the Bijawars, as if thrown against the latter by a fault, though the evidence for such dislocation is scant". At the southern portion near Sortipura the Vindhyan scarps rest on the metamorphics. Near the deserted village Bhadlipura the boundary between the breccia and the Vindhyans is marked by a trap dyke which could be traced for more than half a mile, running W.N.W.-E.S.E. and terminating about two furlongs south-east of Sadkhera. Further west there is a small exposure of pink Vindhyan shale which dips steeply to the W.S.W. unlike

the general low dip of these rocks to E.N.E. These features strongly suggest a fault between the breccia and the Vindhyan quartzite. The boundary between these rocks further north near Ponatoga is ill-defined and one appears to merge with the other. South of Ramkola the quartzite with rather a steep dip to the west (40°) rests unconformably on the northerly dipping phyllites. The ground between Ramkola and Barjhar could not be examined in detail. The Choral river here cuts through a deep gorge of the Vindhyans which, according to Blanford (*Op. cit.*, p. 94), is due to their resistance to atmospheric disintegrating action. Near Barjhar the Vindhyans again come against the dolomite and the breccia. In the bed of the Choral river about a mile and a half north of Barjhar there is strong evidence of faulting in the Vindhyans. The cherty breccia at the base of a prominent band of boulder bed at the west bank of the river contains large blocks of Vindhyan sandstone arranged in a topsy-turvy fashion. These embedded blocks may exceed more than 100 feet in length and 20 to 30 feet in width (Plate 20, Fig. 1). Most probably Blanford (*Op. cit.*, p. 94) came across the same exposure but he was not very sure about a fault. He, however, noticed a distinct fault traversing the Vindhyans in the bed of the ravine little to the north. The writers did not notice any fault in the neighbouring ravines although folding in the quartzite is a common feature there.

The trap spreads over the Vindhyans for a considerable area east of the Choral river and forms a very irregular boundary. At the northern slope of the quartzite ridge, north of Nagjhiri, there is a persistent band of breccia which marks the southern boundary of the Lameta sandstone. Further west near Mehdikhera there are numerous abandoned pits in the breccia from which iron-ore was obtained for local smelting. This breccia is a part of the large exposure which extends up to the Kanar river. This breccia and the quartzite to the south occur in juxtaposition. The previous observers considered this boundary to be a faulted one. According to Bose (*Op. cit.*, p. 15) the fault is traceable for a distance of 20 miles from Ranjna to Bhaurikhera. Blanford (*Op. cit.*, p. 94) considered that the fault "must be of very considerable throw, probably many thousands of feet". The present writers are of the opinion that although the breccia at the supposed fault is indistinguishable from the large spread of

the intraformational breccia to the north, the nature of contact suggests a fault between the Vindhyans and the breccia.

The Vindhyans are mainly represented by a hard, compact quartzite. Whitish massive quartzite with irregular streaks and patches of purple is the most prevalent type. Quartzite of more uniform shades of pink is occasionally observed. Dark brown ferruginous quartzite crops out in the Choral river west of Bekha. Blanford also noted that the prevalent rock of the Vindhyans is a quartzite rather than a sandstone. According to him (*Op. cit.*, pp. 43-44) " It is purely quartzose, translucent, and has at times almost the appearance of being crystalline quartzite. On its fracture it has the appearance of conchoidal form of quartz. It is clearly intermediate between a quartzite and a sandstone ". Gritty sandstone, with pebbles of quartz, up to half an inch across, was noticed at the base of the quartzite scarp east of Sortipura. This rock has the general appearance of Lameta sandstone in the neighbourhood. Shale, mostly pink and laminated, occurs near Sadkhera and Sorti Barol. The former, as mentioned before, occurs in the breccia and the latter at the base of the quartzite in the *nala* section south of the village.

Post-Vindhyans

Breccia

The breccia which occupies large portions of the upper Narbada valley and extends up to the present area has drawn considerable attention from the previous workers. Various explanations have been put forward to account for the origin and actual mode of occurrence of this rock. J. G. Medlicott (*Mem., G.S.I.*, II(2), pp. 244-249, 1860) in his account of the pioneering work which he carried out in the area mentioned that among the rocks occurring in the valley of the Narbada, few rocks appear more frequently or attract more attention of the geologists than the breccia. He considered the breccia to be afault rock occurring " in line " and cutting the schists obliquely. His accounts of the mode of occurrence of the rock are not very convincing to ascribe it to be a fault rock. He wrote that " the direction of the hill ridges (E.-W.) is not that of the strike of the schist beds, all the varieties of which may in turn be found at their base, but that these ridges owe their existence to the breccia. This rock is always found on the summit, it may almost always be traced up the east and west sides of these hills, and sometimes across

the flat ground from the east of one to the west of another of them, while on the north and south the schist beds only are seen, except that in most cases fallen masses of the breccia greatly obscure the real structure of the ground, and in some these are so numerous on the north and south slopes of the hills that it is impossible to discover where the breccia is in place, and where only accidentally present, as fallen from the higher part of the hill ". Most probably the exposures of which Medlicott gave the above account are real summit beds. As mentioned before, Blanford, on the authority of Mallet, included the dolomite and breccia in the Bijawars. That these workers were not free from confusion regarding the origin and age of this rock is clear from the account of Blanford about an exposure of this rock near Andhari Bag which is associated with limestone. He wrote (*Op. cit.*, p. 36) " Brecciation indeed is extremely common throughout all the beds of the series (Bijawars). In places where the limestone and quartzite join, masses of each are found enveloped by the other, as though the whole had been crushed and ground together. At the same time there appears reason for believing that the phenomenon is not confined to this series, but that it is occasionally manifested amongst the lower beds of the overlying Vindhyans ". He was, however, more definite when he wrote (*Op. cit.*, p. 97) " The breccia and the limestone are perfectly distinct, and do not pass into each other, yet they are most strangely mixed together ". Although Bose (*Op. cit.*, pp. 12-13) retained the rock in the Bijawars, he regarded it to be of fault origin. According to him " along faults it is never missed ". He was, however, not very confident about his findings when he wrote that " Away from faults, the breccia alternates with the limestone, but there did not appear to me any method in the succession ". Vredenburg and Fermor considered the iron-bearing breccia near Mehdikhera as a fault rock and the manganese-bearing breccia as a " coarse conglomerate at the base of the Lameta series ". Fermor later wrote (*Op. cit.*, p. 673) " The Bijawar rocks seemed to have been lateritised at the surface in the pre-Lameta times by a process analogous to that by which the post-trappean laterites have been formed. This pseudo-laterite has been designated ' porous breccia ' by Vredenburg, and is composed of angular fragments of quartz, hornstone, quartzite, etc., set in a soft porous, loamy matrix. In many cases this porous breccia has

probably been formed directly from the hornstone or chert-breccias; but it is not certain that this is always the case, and the other rocks, such as siliceous limestones, may not have given rise to some of the porous breccias. The lowest Lameta beds probably consist sometimes of this porous breccia re-arranged by water, so that it is often impossible to decide where the latter ends and the Lameta begins".

The breccia which occupies a large portion of the area surveyed crops out in fairly big patches, each measuring a few square miles in area. The main exposures are confined to the existing river channels. The very mode of occurrence of this rock suggests that it is not a normal fault rock but occurs as irregular masses occupying depressions of the post-Vindhyan erosional surface. The evidences leading to the above conclusion will be dealt with when the individual outcrops are discussed. It is a massive rock attaining up to a thickness of more than 150 feet in which no sign of stratification is noticed. Most commonly the rock is a pink and red jaspery breccia containing angular fragments of quartz, jasper, white or horny chert set in a jaspideous cherty groundmass (Plate 20, Fig. 2). The fragments may be triangular, cubical, rectangular or irregular in outline. The distribution of the fragmentary material is very irregular. Another common type of the rock is a calcareous breccia in which the above fragments are set in a calcareous matrix. The manganese-ore of this area is mostly confined to the latter type of rock. Sometimes the jaspery breccia occurs as irregular patches in the calcareous rock. Thus, calcareous breccia occasionally resembles an altered dolomite. It gives an appearance as if the quartz and chert fragments have been derived by a crushing of the bands of the same material in the dolomite. At places the rock is clayey or loamy limonitic. White brecciated chert with angular pieces of white vitreous quartz occupies fairly large patches. In the Choral river section east of Barwaha boulders of the pura and south-east of Mehdikhera. Conglomeratic breccia containing boulders of quartzite and breccia are not uncommon. In the Choral river section east of Barwaha boulders of the Vindhyan quartzite, up to a few feet across, occur embedded in the mass of breccia.

The writers are tempted to quote J. G. Medlicott who gave a very apt description of this rock from the neighbouring areas.

He wrote (*Op. cit.*, pp. 244-245) "It generally is found in amorphous masses of a reddish colour, sometimes with a honey-combed surface as if from the weathering of a porous or vesicular rock, sometimes presenting smooth rounded outlines with the polished metallic look. .... It is extremely tough, has a conchoidal fracture, and the freshly broken surface often presents a horny flint-like appearance. On such a surface there may generally be traced the outline of angular fragments enclosed in the rock ; commonly, however, the material of which the enclosed fragments are composed is so similar to the matrix to which they are embedded, that it is often difficult to detect their presence. Sometimes a slight difference in colour, or texture, between the two, suggests the true state of the case".

Under the microscope, the fragments of breccia consist of angular pieces of chert, jasper and quartz. The chert and jasper fragments do not indicate much shearing, although occasional cracks, filled with jaspery or calcareous material are seen. The quartz fragments are occasionally sheared, showing granulation and pronounced strain shadow. The groundmass of the cherty breccia is generally made of jaspery or white cryptocrystalline silica. In the calcareous rock the groundmass is mostly calcite, showing various stages of replacement by silica. In the manganese-bearing breccia the ore occurs as dusty oxides in the groundmass or segregated patches; the latter appear to be common in the calcareous material.

The following are the main exposures of breccia in the area:—

The largest exposure of this rock occurs in the valley of the Choral river from Barwaha to about a mile south of Ramkola. The Choral river cuts a deep channel through the breccia which extends up to a mile on both sides of the river forming a rugged hilly country. In this section there are occasional small inliers of phyllites, schists and dolomite (Plate 20, Fig. 3). At the eastern side of the river it spreads over as a capping on the phyllites and schists. The thickness of this mass increases from the west to the east attaining more than 300 feet at the left bank of the river on the ridge ·990, north of Sortipura. At the extreme limit to the west it occurs as a thin capping not exceeding 100 feet in thickness. As mentioned before, its boundary with the Vindhyans near the deserted village Bhadlipura is marked by a trap dyke and further north the boundary is ill-defined. At

the western side of the river the exposure is frequently concealed by the trap and occasionally by the Lametas. South of the sandstone scarps of Ghatia it rests on the dolomite. Apart from this large patch of sandstone there are few other isolated cappings of this rock on the breccia in the vicinity of the temple of Jayanti Mata. The rock is predominantly a red jaspideous breccia but near the palace immediately east of Barwaha it passes into a soft loamy rock in which the fragmentary material is not very conspicuous.

South of the palace, trap comes in but the breccia is again exposed over a fairly large area forming hills and ridges north of Rupabardi and extending up to the Narbada river, the southern limit of the area examined. The trap which lies at the western side of the breccia here occupies a much lower level; the boundary running at the base of the ridges formed of the latter. The nature of the eastern boundary with the band of quartzite has already been mentioned. The breccia at the sharp bend of the river south of the road to Sortipura contains large boulders of quartzite and occasionally of cherty material. The quartzite boulders, up to three feet across, are pink and fine-grained and resemble the Vindhyan quartzite of the neighbouring area (Plate 20, Fig. 4). Further south, boulders of white chert are common in the river bed. This material disintegrates to a fine powder under the hammer. There is another conglomeratic type of this rock which occurs at the western side of the tank at Sortipura. It contains sub-angular or rounded pebbles of chert in a gritty and sandy matrix. The jaspideous breccia south-east of Sortipura occasionally contains flaky hematite.

Fringing the margin of trap there occurs an interesting exposure of this rock near Mohada. The exposure, averaging about 50 feet in thickness, is sandwitched between the trap at the top and dolomite at the base. This nature of exposure is expected of a horizontally placed mass. The uniform dip and strike of the underlying dolomite also lends support to this inference. This breccia contains small patches and stringers of manganese oxide (wad, pyrolusite or psilomelane).

Manganese-bearing breccia is again exposed north of Nandia. It forms low mounds in the trap covered country with occasional exposures of dolomite at the peripheral region. Small cappings of trap are still left on the highest mounds of breccia.

The breccia is mainly of a calcareous type and manganese oxides are often segregated in it. The senior writer has given detailed accounts of the occurrence of manganese in this area in his earlier unpublished reports. Jaspery breccia occurs as irregular patches in the calcareous rock. On the mound north-west of Nandia boulders of chert or jaspery breccia are found embedded in the more calcareous rock. Near Agarwara a white massive cherty breccia, often decomposed to a white powdery mass near the surface, forms a mound about half a mile in length. At the southern side this breccia is overlain by calcareous beds which resemble the coralline limestone, exposed at the base of the mound to the west.

Breccia around Barjhar also forms ridges and mounds. These mostly lie on the western side of the Choral river and stand out conspicuously from the surrounding trap country. Its boundary with the Vindhyan rocks to the east is not very clear. Near this boundary at the left bank of the river there is a prominent mound of breccia which runs parallel with the river. If this ridge indicates a fault, then it is difficult to explain the presence of the unaffected dolomite which is exposed immediately to its south. Moreover, the breccia spreads over a low country at the right bank of the river. This particular exposure suggests that if this rock is pre-Vindhyan then one should expect the Vindhyan rocks at the right bank of the river, particularly on the mounds which attain higher altitudes than the basal beds of the Vindhyans on the left bank. The same conspicuous absence of the Vindhyan rocks is also observed on the right bank near Sadkhera. If the breccia was not formed prior to the deposition of the Vindhyan rocks, then it is either a fault rock or post-Vindhyan. As already mentioned it is difficult to conceive fault rocks being exposed as large spreads as in the present case. Thus the breccia most probably occupies depressions on the post-Vindhyan erosional surface.

The Kanar river flows through thick masses of breccia occurring east of the deserted village Kanksiakhera and again from a point about half a mile south of its confluence with the Satbhairon *nala* to its confluence with the Lohar *nala*. The outcrops are concealed by the Lametas which crop out over a large area at the western side of the river. As the sandstone gradually recedes away from the river, the southern exposure widens out

towards south and near Mehdikhera it occupies a fairly large ground. The breccia probably extends further west and connects with the conglomeratic breccia which is occasionally exposed at the base of the sandstone in the *nala* sections south of Katkut. The relation of the breccia with the dolomite here is rather peculiar because both the rock types attain the same height forming steep banks of the river. This is hardly expected if the breccia really overlies the dolomite. Moreover, no breccia occurs between the dolomite and the sandstone at the right bank of the river. Unfortunately the contacts between the dolomite and the breccia are not clear enough to ascertain their actual relationship. Mention has already been made of a small exposure of dolomite east of Kanksiakhera with a slip surface to its south. A small outcrop of dolomite in the fashion of an inlier occurs south-east of the abandoned stone-quarries. Though the breccia is predominantly jaspideous, softer dolomitic types are quite common in the area. Some of the latter types of breccia contain fragmentary quartz which appears to have been derived from the siliceous bands in the dolomite due to disruption. In fact, at places the neighbouring fragments of this mineral may be fitted in to form distinct bands. Considering all these aspects it may be explained that the breccia was formed due to the subsidence of dolomite in the solution caves followed by silicification of the fragmentary rock. The outcrops of dolomite which occur as inliers in the breccia may be the unaffected blocks in the debris. If the subsidence is considered to have occurred after the Vindhyan rocks were formed then the boulder of these rocks in the breccia can be accounted for.

The breccia south and south-east of Mehdikhera is faulted against the Vindhyans. The fault breccia is marked by deposits of hematite which were worked in the past for the indigenous smelting of iron. In a deep well about a furlong north of the village the writers observed boulders of gritty sandstone in white cherty rock. This fault rock probably extends to the west and connects with the breccia exposed at the base of the ridge north of Nagjhiri.

Boulder Beds

The boulder beds of the area drew particular attention due to their peculiar distribution on the banks of the Choral river and

due to their mode of occurrence as lenticular masses. The outcrops, four in number, range from a small patch extending over only a few square yards of area to the thick bed which runs for a distance of about three furlongs at the right bank of the river, east of Bekha. Absence of bedding even in the thick exposures, imparts a distinctive feature to this rock from the bedded conglomerate in the Lametas. Horizontal joints which are occasionally developed in the thick deposit west of Bekha give the impression of bedding planes. The boulders are mostly of Vindhyan quartzite but occasionally consist of breccia, chert and jasper. These, ranging up to six inches across, are set in a ferruginous quartzose matrix.

The southernmost exposure which occurs as a pavement on the left bank of the river, about a mile north of the temple of Jayanti Mata, is situated immediately north of a faulted block of Lameta sandstone. The small gap between these rocks is occupied by the chert breccia.

A sloping pavement made of recemented boulders of quartzite and breccia occurs by the side of a steep wall of the Vindhyan quartzite at the sharp bend of the river, half a mile east of Barjhar. Prominent joints and minor faults are common in the quartzite in the vicinity of the boulder deposit. There is another small outcrop of this material in the river bed south-east of the village. It rests on the sloping surface of the breccia.

The thick boulder bed west of Bekha is confined to the right bank of the river and lies on the Vindhyan quartzite as well as on the breccia. The absence of this thick bed at the left bank of the river is very conspicuous. The boulder bed gradually thins out to the south and ultimately rests on a much fractured Vindhyan quartzite. As mentioned before, these blocks of quartzite are probably embedded in the breccia. The boulders are of Vindhyan quartzite. No boulder of breccia could be noticed, even when the boulder bed directly rests on it.

Although the stratigraphical position of the boulder beds is the same as the basal conglomerate of the Lameta formation these are distinguished by their massive character, peculiar mode of occurrence and containing much larger boulders than the usual Lameta conglomerate. The boulder deposits, unlike the Lameta conglomerate, are not associated with the arenaceous sediments. Inspite of these characteristic features it cannot be

altogether ruled out that the boulder beds might have been deposited during the early periods of the Lameta age.

Bagh Beds

Bagh beds in this area are mainly represented by the coralline limestone with occasional intercalations of sandstone. The exposures in this area are the easternmost occurrences of the Bagh beds of the Narbada valley. The limestone has the typical mottled granular appearance with segregated clusters of fossils, mostly *Ostrea* and other bivalves. Bose (*Op. cit.*, pp. 23-24) noted a patch of Nimar sandstone, the basal member of the Bagh beds, in the *nala* section near Yelam. It was noticed by the writers that the sandstone in this section occurs as intercalations in the limestone. Probably the limestone which is exposed at the base of the sandstone beds was covered when Bose visited the area. It appears he was also misled by a recent bed of conglomerate which occurs immediately south of the limestone exposure. He included this recent deposit in the Nimar sandstone. The exposure of this limestone at the base of sandstone ridge south of Ghatia drew particular attention of Medlicott and Bose. Bose accepted the interpretation of Medlicott (*Op. cit.*, p. 75) who came to the conclusion that the limestone rests on the denuded surface of the sandstone which forms the Ghatia scrap to the east. The present writers do not agree with the above view and consider that the limestone in all probability underlies the sandstone.

The limestone near Yelam occurs as flat or gently dipping pavements at the bed of the *nala*, east of the village. It is exposed for about a mile and is thickly covered by the trap near Pirakalan. There are two exposures of sandstone in this section. The southern one, forming steep banks of the *nala*, extends for more than a furlong in length. It rests on the undulating surface of the coralline limestone and passes upward into a thin bed of the same limestone. The sandstone is fine-grained and thinly bedded with calcareous partings. It appears to occur as a lens-shaped body with a maximum thickness of about 20 feet. The northern exposure of this rock is much thinner and consists of white friable sandstone. At the bend of the *nala* near Pirakalan the coralline limestone rests on an outcrop of steeply dipping dolomite.

There are a few small exposures of coralline limestone near Agarwara. Immediately west of the village it forms pavements which show frequent oblique laminations which dip at a low angle to the west. Granular mottled limestone but more massive in character is exposed in the *nala* south of Naya. In the debris from the pit north-east of Agarwara coralline limestone was noticed. The senior writer who earlier examined this pit while it was being dug, did not notice any limestone in the section. He could see altered trap, inter-trappean limestone, red shale and gritty sandstone from the top to the bottom. The limestone now observed in the debris must have been obtained from deeper excavation. About half a mile south-east of Agarwara and on the mound of the cherty breccia there are occasional thin beds of granulated limestone. This rock also shows oblique laminations and is lithologically very much like the coralline limestone exposed west of the village. Most probably these outcrops are part of the same rock separated by later erosion. At the place where the cart-track from Nandia to Naya crosses a stream, in between, there is another small exposure of limestone which though more siliceous and disturbed, has the granular appearance and laminations of the coralline limestone. The flat-country between Agarwara and Yelam is covered by black soil with occasional exposures of trap. In this area there are a few interesting patches of raised ground covered with greyish white soil with occasional slabs of coralline limestone strewn over the surface. From a distance, these look like weathered outcrops of coralline limestone but on closer examination these are found to be the sites of abandoned villages.

About a mile and a half north-west of Barwaha and at the northern side of the trap mound ·724 there crops out a small exposure of coralline limestone. The same rock is also exposed to the west in the railway cutting. There is a fairly large outcrop of dolomite within a very short distance to the north and apparently the coralline limestone rests on it. But the absence of this limestone on the exposures of dolomite in the neighbourhood suggests that the rock was deposited in a small basin. The limestone here contains a rich assemblage of fossils. According to Blanford (*Op. cit.*, pp. 102-103), who did not miss this small outcrop, the limestone contains fragments of *Ammonite* and *Belemnite,* oysters, *Astarte*. *Terebratula* and fossilised wood.

The limestone exposed south of Ghatia is a flesh-coloured granular mottled rock. It occurs in a depression at the western side of the sandstone scarp of Ghatia and runs along a shallow water course for a distance of two furlongs as a narrow elongated strip.

On being requested by Medlicott a shallow pit was sunk in this limestone by Mr. Moore, one of the engineers at the railway viaduct on the Narbada and had supplied the following description of the pit:—

1′ 6″ Entirely of oyster shells.

9″ Thin bed of conglomerate with fossils embedded.

3′ 3″ Bed of soft white sandstone ; first foot excavated with a pick ; the rest harder and distinctly stratified with perfectly level beds.

4′ 6″ Thick bed (bottom not reached) of water-worn pebbles and small boulders embedded in stiff yellowish-brown clay or loam.

Medlicott wrote (*Op. cit.*, pp. 73-74) " One could scarcely desire a more distinct case of a wide geological break than is presented in this section : the petrographical contrast is evident enough from the foregoing description, suggesting in the strongest manner the necessary distinction of the formations. The case of unconformity may not be considered conclusive: a small fault between the oyster bed and the scarp to the east of it would account for the actual relative positions ; a concealed sharp curve in the bedding would have the same effect ; or it might be an original great bank of sand with the muddy oyster bed alongside of it. Nothing short of an artificial cut across the rocks could finally dispose of all these objections ; but certainly the first and most probable explanation is that of original denudation-unconformity ".

According to the present writers the very fact that the limestone rests on dolomite proves that it lies under the sandstone. Moreover, the gritty or pebbly sandstone reported from the pit, may be equivalent to the Nimar sandstone, the prominent basal member of the Bagh beds at the western side of the valley.

Lametas

The group of rocks consisting of conglomerate, grit, sandstone and limestone, which spread over a large area around Katkut

and forms prominent ridges near Ghatia was the subject of conflicting opinions amongst the previous observers regarding their actual stratigraphical position. Blanford mapped these rocks as Bagh beds and Mahadevas. According to him (*Op. cit.*, p. 100) these beds " have much the appearance of Mahadevas ", but at the same time he wrote "there can be little doubt in assigning these rocks to the cretaceous series, so much developed further to the west ". During his work in the area it was generally considered that the Mahadevas were equivalent to the Lametas. Later work has shown that all the rocks known as Mahadevas in the Narbada valley belong to the great plant-bearing series, the youngest member of which is the Jabalpur group of the Jurassic age and the Lametas lie unconformably on this group. Medlicott (*Op. cit.*, p. 73), based on a local information, came to the conclusion that the sandstone of Ghatia belongs to the true Mahadevas resting unconformably below the limestone. He also suspected that the sandstone near Katkut belongs to the same group. Vredenburg and Fermor found typical Bagh fossils in the basal conglomerate of this formation. They, therefore, could not agree with Medlicott and Bose who correlated the rocks with the Gondwanas and came to the conclusion that " Dr. Blanford's original correlation of these beds with the Lametas was correct". C. S. Fox who lately visited the Dhar Forest (The mineral resources of Dhar State, Central India, 1946) held the view that the sandstones of the Dhar Forest belong to the Mahadevas. Although the present writers did not come across the fossiliferous conglomerate reported by Vredenburg and Fermor, they have shown that the limestone near Ghatia, which led Medlicott to differ from Blanford. actually underlies the sandstone. This settles the Cretaceous age of the sandstone. The writers while working in the valley of the Man river, where the Cretaceous rocks are best developed, have noticed that a thick zone of sandstone with intercalations of shale and limestone, containing numerous pieces of fossil wood, rests conformably on the coralline limestone. It may be mentioned here that drift fossil wood was also recorded from the sandstone near Ghatia.

The sandstone near Ghatia stands out from the neighbouring country as a prominent ridge with occasional steep escarpments at its margins. It mostly rests on steeply dipping beds of dolomite and partly on massive breccia. At the north-west corner

it is covered by the trap. It is a hard gritty sandstone with occasional thin bands of conglomerate. Medlicott (*Op. cit.*, p. 73) has left an apt description of the above sandstone when he wrote " It is hard white rock with red streaks and mottling. Pebbles (chiefly of Vindhyan quartzite) are scattered through it locally so as to form a conglomerate; but even in the clearest sections in the quarries no regular bedding is visible, the strings of pebbles, however, indicating that the mass is undisturbed. Well marked joint-planes traverse it in various directions ". It is a thoroughly consolidated rock, though portions of it are much harder than others through infiltration of silica from the superincumbent trap. No earthy layer is found in it. Another thick bed of sandstone forming a detached hillock on the breccia occurs immediately south of the above exposure. The rock here is predominantly white and felspathic. The conglomeratic bands contain sub-angular and rounded pebbles of jasper, chert and quartz.

Gritty ferruginous sandstone forms a few low mounds on the ridge of breccia south of the temple of Jayanti Mata. Thin pavements of conglomerate are also occasionally exposed at the base of the sandstone. Further south and in the small valley along which runs the forest road from Barwaha to Sortipura, there is a thin bed of conglomerate resting on the upturned edges of quartz-sericite schist and overlain by a gritty felspathic sandstone. At the western side the conglomerate is covered by the trap flows. The occurrence of these rocks in a depression suggests that the topography of the country on which they were deposited was not much different from what is observed to-day. The pebbles of the conglomerate are normally one to two inches across but larger boulders are also noticed. The pebbles and boulders are mostly of Vindhyan quartzite and less commonly of jaspery material. Occasionally the quartz boulders themselves contain pebbles of jasper. The exposure of sandstone near the temple of Jayanti Mata and lithologically similar to the gritty rocks of this formation appears to be a faulted block; the higher ground to the east being occupied by the breccia. At the southern side it makes an abrupt contact with phyllite and at the northern side it is much folded and plunges steeply in the river bed. On the face of the steep wall of sandstone at the left bank of the river large boulders of the same rock are found to be embedded.

The sandstone which crops out in the *nala* section north-west of Agarwara is probably the continuation of the rock exposed in the pit, north-east of the village. The sandstone in the pit is exposed at a depth of 21 feet from the surface. Within a distance of about 1,000 feet to the east of the above pit there are other pits exhibiting only breccia even at their bottoms which measure more than 35 feet in depth. This proximity of the rock types could easily be explained by a fault in between but as no disturbance is noticed in the flat-bedded sandstone such an explanation would be difficult to accept. Most probably the sandstone with the suspected underlying bed of limestone rests on a steeply eroded surface of the breccia.

The largest exposure of the Lameta rocks occur near Katkut. These rocks, represented by conglomerate, grit, sandstone, shale and limestone, emerge out of the trap in the stream sections near Chandupura and gradually widen out to the south where these occupy a fairly extensive area forming a more or less flat country. The predominant rock is a red or pink soft sandstone. It is mostly confined to the eastern side of the exposure and approximately lies east of the line joining Kanai Mata to Karondiakhera. Around Katkut and south of the road from this village to Mehdikhera the predominant rock is a white calcareous sandstone, often grading into an arenaceous limestone. The calcareous rock hardly exceeds 8 to 10 feet in thickness, whereas the pink sandstone to the north occasionally attains more than 100 feet in thickness. Due to the decrease in thickness of the rocks to the south there are frequent exposures of the underlying breccia in the *nala* sections. This thinning out of the rocks and the similarity of the calcareous breccia often renders it difficult to trace the boundary with accuracy. North of Nagjhiri the calcareous sandstone rests against the Vindhyan quartzite. This mode of occurrence and the presence of breccia, noted earlier, are strongly suggestive of a fault in between. The boundary between these formations further west is concealed by a large spread of trap. Near Sorti Barol, however, a small exposure of conglomerate and sandstone, lithologically similar to the Lametas, rest on the Vindhyan sandstone. The absence of the Lametas between the trap and the Vindhyans in the Choral river suggests that these rocks do not extend much to the west of the inlier at Nimi. The sandstone exposed in the section of the Kanan

river near Chandupura is a coarse felspathic gritty rock with thin bands of conglomerate and shale. The exposures of these rocks, occasionally intruded by the trap dykes, could be traced northward up to the deserted village of Malharganj. Grit and conglomerate resting between the granite and the trap were also noticed almost up to the same distance to the north in the next stream section east of the Kanar river.

The pink medium-grained sandstone with thin bands of conglomerate and shale is best exposed in the Sukuli *nala* near Okhla. Pebbles of quartz and chert are quite common in this rock and occasionally they are segregated to form thin bands of conglomerate. False bedding is a conspicuous feature of this rock. It is either horizontally bedded or shows a gently rolling dip; the prevalent direction being to the S.W. Near Okhla this rock has occasionally been thrown into gentle folds. The gritty quartzite on the mounds near Kanai Mata is the topmost portion of this rock which has been silicified due to its direct contact with the trap. The beautiful temple at Okhla was made out of this pink sandstone. This sandstone was also extensively quarried in more recent years for constructional purposes.

Around Katkut the pink gritty sandstone occurs only on the higher grounds whereas in the *nala* sections calcareous grit or sandstone is exposed. In the *nala* north of the village there are pavements of pink arenaceous limestone. It is coarsely crystalline and resembles the Lameta limestone near Bagh. Whitish calcareous grit and sandstone are the predominant rocks south of the village. The decomposition of these rocks often gives rise to marly material which is being used for local white-wash. The basal portion of this grit is occasionally conglomeratic with boulders of breccia in a calcareous groundmass. It is often difficult to distinguish between the conglomerate and the breccia; the latter rock being mostly calcareous, containing pebbly material. Thin bands of conglomerate containing only pebbles of Vindhyan quartzite are also common.

Deccan Trap (Malwa Trap)

Flows of the basaltic lava belonging to the Deccan Trap rest irregularly on all the rock types of this area. The basal flows of the trap were poured over a country, the configuration of which

was as irregular as the present day topography. If the pre-trap country is reconstituted it will be observed that the main drainage of that country more or less coincides with the present Choral river. The earlier workers in the area were also struck by the irregular land surface on which the lava flows came to rest. Blanford wrote (*Op. cit.*, p. 102) "The base of the trap here is very irregular. The cretaceous beds only underlie them in patches; frequently the trap rests directly upon either the Bijawurs or the Vindhyans. A better study of unconformity could not be washed than around Burwai—Vindhyans upon metamorphics and Bijawurs, cretaceous beds upon Bijawurs and Vindhyans, trap upon all four, each unconformable upon the other, though the degree of unconformity varies in each case". The work of Vredenburg and Fermor was an interesting contribution to the physical geography of the old land area. The report runs (*Op. cit.*, p. 21) "The filling-up by the lava flows of the old ravines cut in the Lameta sandstones has led some previous observers to false conclusions with regard to the relative ages of some exposures of Lameta sandstone and adjoining trap. Near Chandgarh, for instance, where the Narbada cuts through a thick conglomerate bed, the latter, on account of its high level, was formerly taken to be sub-recent accumulation in the river valley; but Mr. Fermor, who crossed the exposure early in the season, was struck by the absence of basalt and agate pebbles amongst the boulders, as one would expect in a conglomerate formed at the expense of the Deccan trap. On returning later on, in accordance with Mr. Vredenburg's instructions, to examine the exposure more critically, it was found that the apparent higher position of the conglomerate was due to the Deccan trap having filled in a deep valley in the Lameta beds".

The basalt is most commonly of a coarse porphyritic type. At the surface the rock weathers into rounded boulders. At the northern portion of the area mapped the rock is of finer grain and is well-joined, often showing columnar structure. At the base of the ridge near Borkhera there are interesting exposures of a medium-grained basalt which has developed close joints resembling schistose rock. The joint planes are often inclined to the horizontal surface on which the rock rests here. No sign of shearing is noticed even under the microscope. The lava flows are mostly olivine basalts. These are commonly porphyritic with

laths of plagioclase (labradorite) ophitically arranged in a groundmass of augite, olivine, glass, iron oxide, etc. The olivine is frequently altered into yellowish or greenish chrysotile. Palagonite and iddingsite are present. Xenocrysts of quartz with reaction rims of granulated augite occur in the basal flows.

The village Narsingpur rests on the saddle of a ridge which is conspicuously elevated like a dyke from the surrounding country covered by black soil. Trap dyke forming a low ridge marks the boundary between the breccia and the Vindhyan quartzite north-west of Bhadlipura. Thin dykes of trap cutting through the Archaeans and the Lametas occur near Sortipura and Malharganj respectively. The trend of all these dykes, running almost E.-W., is conformable with the general alignment of the numerous dykes reported from this valley. Unlike the coarse vesicular and altered flows of the area the dyke rocks are fine-grained and have a fresh look about. Doleritic texture is better preserved in these rocks. The constituent minerals are more or less the same as in the flows.

In the pit north-east of Agarwara a bed of limestone, about 5 feet in thickness, is exposed at the base of a thin capping of black soil. Underlying the limestone is a 12 feet bed of red clayey material which is most probably a decomposed 'red bole'. The limestone contains *Physa prinsepii*, *Unio* sp., etc. North of the pit and at the base of trap there are fragments of silicified fossil-wood and *Physa* which are strewn over the surface with fragmentary chert. This fossiliferous chert bed most probably overlies the fragmentary chert quite common in the neighbourhood. In the railway cutting south-west of Chor Bauli there is an exposure of lens-shaped mass of chert in the trap. Intertrappean limestone also occurs in the *nala* section south of Yelam and on the upper slope of the hillock east of Rupardi. The latter occurrence is more persistent and contains numerous fossils of *Physa prinsepii*.

Recent

The recent deposits of the area consisting mostly of clays, sands and gravels are of minor occurrence. The area surveyed is mainly a rocky country with hardly noticeable flats of thin sandy or clayey alluvium. The thicker soil cappings are con-

fined to the areas covered by trap or its marginal areas. The cultivated grounds, even when situated quite far from the main trap outcrops, are on the black soil, most probably derived by the residual weathering of the outliers of trap. The main patch of alluvium occurs near the Narbada river in the vicinity of Barwaha. West of the town, the thickness of the alluvium occasionally attains more than 20 feet and probably more near the river. In the *nala* section west of Agarwara there are exposures of fairly hardened sand beds below the thin mantle of trap soil. It is not known whether these are reconsolidated sandy soil with loamy material or due to the weathering of calcareous sandstone which is exposed in the neighbourhood. A recent pebble bed, containing pebbles of trap, set in a calcareous matrix, crops out at the right bank of the *nala* south of Yelam. At the bank of the Narbada south-east of Barwaha there is a fairly thick bed of alluvium made up of sandy soil which forms a badland topography. In the river bed, however, trap and the underlying rocks crop out. In the bed of the river near the railway bridge there is a deposit of coarse sand about three furlongs in length and 10 to 15 feet in thickness. This meets the local demand of the material for building purposes.

GEOGRAPHICAL INDEX

GEOGRAPHICAL INDEX—*contd.*

FOSSIL PYCNODONT FISH TEETH FROM RANIKOT, SIND.

BY K. N. PRASAD, B.SC. (MYS.), B.SC. (CAL.), AND V. RAGHAVENDRA RAO, M.SC., PH.D., *Geological Survey of India.* (With Plate 21.)

CONTENTS

ABSTRACT

A part of mandible of a Pycnodont fossil fish collected by F. Fedden from the marine formations of Sind was provisionally identified by him as *Phyllodus*? or *Periodus*? Recently a re-examination of the fossil by the authors revealed that it belongs to an entirely different genus *Coelodus* Heckel. The only occurrence of this genus in India is in the Eocene beds of Assam (1952). The specimen under description shows a close resemblance to *Coelodus parallelus* Dixon, from the Turonian of Sussex, but the Sind specimen differs from the latter from the indistinct marginal ridge surrounding the base of the dentition and its comparatively narrower outline. Hence the species described in this paper is considered a new variety, *Coelodus parallelus var. feddeni*.

As regards the age of the fossil, it was assigned by Fedden to infra-nummulitic but later Blanford regarded the age of the beds in which the fossil was found, as Upper Cretaceous due to its association with *Cardita beaumonti* (*Venericardia beaumonti*) and other Invertebrate fossils. But recent workers on the Tertiary rocks of North-West India assign the age of the *Venericardia* beds to Palaeocene.

INTRODUCTION

The specimen described here, was collected by F. Fedden, during his field investigations in 1875-76. The specimen comes from the Barki *nala* on the road to Lohi Lak pass on the eastern side of the range of hills, north of Ranikot, Sind. The forma-

tion mainly consists of "impure limestones and calcareo-argillaceous shaly beds more or less sandy and gypseous". Fedden registered the horizon of the fossils as "Ranikot Series (Infra-Nummulitic)" which was subsequently corrected as Cretaceous by W. T. Blanford. He provisionally identified the fish teeth, embedded in the limestone as belonging to the genus *Phyllodus* ? or *Periodus* ? A re-examination of this specimen in the light of recent knowledge proves that this fossil belongs to the genus *Coelodus* Heckel. Besides this, Fedden collected a large number of Invertebrate fossils found in close association with the fish teeth. His preliminary identifications revealed the following fossils: *Ovula* or *Cypraea* cf. *antiquata, Ovula*? *ellipsoides*, ?*Natica, Strombus*, etc. ?*Cardita beaumonti* (from shales rather higher than the rest), *Corbula harpa*, *Ostrea*, ?*Nautilus lebechei*, *Echinolampas, Schizaster* cf. *baluchistanensis*, small stem like Corals, compound Corals on single base disc and teeth of ? *Phyllodus* or? *Periodus*.

GEOLOGY OF THE AREA

The geological formations met with in this area, range in age from the Cretaceous to the Eocene.

A section of the rocks near Ranikot as given by W. T. Blanford reveals the following zones:—

Boulder Alluvial deposit

Alveolina limestone

Variegated clays and sandstone

Trap

The geological sequence in Sind has been discussed by W. T. Blanford (1876) in a review of the rocks of the Ranikot or Infra-Nummulitic formation. Blandford refers to a small fossiliferous band of calcareous shale and limestone some distance below the base of the white Nummulitic (Khirthar) limestone, interstratified with sandstones and shales, as belonging to the Ranikot group. These bands contain *Cardita beaumonti, Nautilus forbesi*, and *Nautilus lebechi*, in addition to the fossil fish teeth. Since these beds are found interstratified he has not assigned any definite age for this horizon.

DISCUSSION ON THE AGE OF THE FOSSIL FISH TEETH

As seen from the section the fossil comes from the horizon of calcareous shale and limestone, above the traps and below the Alveolina limestone, indicating an age between Upper Cretaceous and Lower Eocene. Some of the associated fossils from this horizon indicate a Cretaceous age while other evidences show Eocene affinities. The presence of the zone fossil *Cardita beaumonti* (?) indicates a Cretaceous age, according to Vredenberg (1906). " these beds must be entirely relegated to Cretaceous". In recent years the geology of Sind has been greatly modified and revised after a detailed study. According to Dr. Krishnan, the *Cardita beaumonti* Beds are regarded as Danian to Maestrichtian, the Lower Ranikot beds (gypseous shales and sandstones with lignite and coal) to Paleocene and the Upper Ranikot Beds (buff to brown Nummulitic limestone and shales) to Lower Eocene. The position of the *Cardita beaumonti* beds has been the subject of serious discussion in recent years. Dr. L. R. Cox (1939) has suggested that the typical fauna of the *Cardita beaumonti* beds, might be of basal Paleocene age rather than uppermost Cretaceous. Dr. Eames (1952) while describing the Eocene succession in Western Punjab, and in the Kohat district, has provisionally included the *Venericardia* shales under basal Paleocene. Reference may be made to Prof. L. Rama Rao's (1940) paper where he has reviewed the Cretaceous-Eocene boundary problems. Further detailed study (microsection) of the matrix and the associated fossils might yield some interesting results regarding the definite age of the fossil.

DESCRIPTION AND COMPARISON

Coelodus parallelus (Dixon) var. *feddeni* nov.

(Pl. 21, figs. 1 and 2)

The fish teeth described here, though fragmentary are fairly well preserved and represent most probably the splenial dentition of a Pycnodont fish belonging to the genus *Coelodus* Heckel.

The arrangement of the teeth is more or less in a definite pattern, consisting mainly of two series of teeth, arranged in parallel rows. The individual teeth are laterally elongated, smooth and have a slightly rounded margin. The principal row shows four teeth, three of which are partly worn on the upper surface. The fourth, is not worn and presents a slightly convex upper surface. The outer row of teeth (inner flanking series) consists of six, closely set transversely elongated teeth. These are not uniform in size but show some slight variation. They are partly worn and consequent to the wear, present a rounded margin at the sides. In the general arrangement, this specimen shows a marked resemblance with the splenial dentition of *Coelodus* Heckel, which was closely studied and compared. The present specimen further agrees closely with *Coelodus parallelus* (Dixon), described and figured by Woodward (1888, 1909), where the general arrangement of the splenial dentition and nature of teeth are more or less similar but show some difference with regard to the form and size of the teeth. In *Coelodus parallelus*, figured here (Pl. 21, Fig. 3) the principal series of teeth are about three times as broad as long, whereas, in the present specimen they are two to three times as broad as long. The inner flanking series is only half as long as broad. Dixon (1850) refers to a distinct marginal ridge surrounding the base but it is not distinct in this specimen. In the general arrangement and nature of teeth, this differs from other described species of *Coelodus*. Hence we have provisionally assigned this fossil to *Coelodus parallelus* variety *feddeni*, after F. Fedden, who collected the specimen.

The splenial dentition is represented by two parallel series of teeth which are transversely elongated, smooth, buff coloured and are firmly attached to the matrix. Several fragments of *Ostrea* and *Trigonia* are found embedded in the matrix. Micro-sections of the matrix have revealed the presence of several miliolids and algae. The associated fossils do not give any definite indication regarding the age of the fossil fish teeth, but on lithological grounds the specimen may be assigned to a slightly higher horizon. It is likely that the assemblage ranges in age from Upper Cretaceous to Lower Eocene. The fossil (G. S. I. Type No. 17474) forms part of the Geological Survey of India collection.

DISTRIBUTION OF THE GENUS COELODUS

The genus *Coelodus* is known to occur in several geological formations of the world ranging in age from Upper Jurrassic to Eocene. Its species are reported from N. America (Lower Cretaceous to Upper Cretaceous), Europe (Upper Jurrassic to Eocene), N. Africa (Upper Cretaceous), Madagascar (Upper Cretaceous), Persia (Cretaceous), Syria (Cretaceous) and India (Upper Cretaceous to Lower Eocene).

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EXPLANATION OF PLATE

Pl. 21, Fig. 1 *Coelodus parallelus* (Dixon) var. *feddeni nov.* splenial dentition. G.S.I. Type No. 17474.

2. *Coelodus parallelus* (Dixon) var. *feddeni nov.* splenial dentition (X3).

3. *Coelodus parallelus* (Dixon). splenial dentition.

Coelodus Jacobi, a New Pycnodont Fish from the Eocene Beds of the Garo Hills, Assam. By

A. G. K. Menon, M.A., M.Sc., *Zoological Survey of India and* K. N. Prasad, B.Sc. (Mys.), B.Sc. (Cal.), *Geological Survey of India*. (With Plate 22.)

ABSTRACT

The fossil material collected by Mr. A. S. Ramiengar from the Middle Eocene Siju Limestone group of rocks in the Garo-Hills, Assam, comprises two series of round teeth and a single oval tooth. From the nature and general pattern of arrangement of the teeth, it has been possible to refer the fossil to the splenial dentition of a fish belonging to the genus *Coelodus* Heckel (Family: Pycnodontidae). In the detailed arrangement of the teeth the fossil does not, however, conform to any of the species so far known, though it approximates to that of *C. fimbriatus* Woodward. It has, therefore, been considered as belonging to a new species and named as *C. jacobi*.

From a study of the distribution of the Indian freshwater fishes of the past, Hora and Menon established that a land bridge stretched across the Tethys sea connecting the Peninsular India with the rest of Asia through the present day Assam until the transgression of the Bay of Bengal during the Eocene submerged it. The occurrence of a marine Pycnodont fish in the Middle Eocene deposits of the Garo-hills has enabled the authors to fix with some reservation the period of the major transgression of the Bay of Bengal as Middle Eocene.

INTRODUCTION

The fossil fish palate, comprising two series of round teeth and a single oval tooth was collected by Mr. A. S. Ramiengar of the Geological Survey of India during his field investigation in the Garo Hills, Assam, during the year 1950-51. It comes from near the village of Eman Gatabalgiri (25°22′ : 90°33′) lying to the south of the Tura Range. According to Mr. Ramiengar, the fossil was not found *in situ*, but was picked up from a cultivated ground, lying close to outcrops of the Siju Limestone (Sylhet Limestone). Several specimens of *Nummulites* and *Assilina* have been found embedded in the matrix of the fossil, thereby indicating its marine nature.

GEOLOGY OF THE AREA

The details of the geology are based on the information kindly supplied by Mr. A. S. Ramiengar of the Geological Survey of India, who surveyed the area in 1950-51.

The lowermost beds of the Eocene present in the area constitute the Cherra or the Tura Stage (Lower Eocene), comprising mostly sandstones and shales with good coal seams. The Tura Stage is overlain by the Siju Limestone group of rocks, comprising mainly limestones with silty shales (Marine), marl and very often sandstones. The fossil fish palate most probably comes from this stage. The limestones are highly siliceous impure for the most part, and are variegated in colour. The rocks are well bedded and massive. On fossil evidence, the Siju Limestone has been correlated with Sylhet Limestone of the Middle Eocene age. The Siju Limestone is overlain by rocks of the Kopili Stage (Rewak Stage) comprising limestones as basal members, with shales and sandstones predominating above. The limestones are usually thin bedded and contain a rich foraminiferal fauna. These limestones pass upwards into thin bedded earthy sandstones, sandy shales and finally into massive well bedded ferruginous sandstone.

Eocene Succession in the Garo Hills

	Feet.
Sandstones and marine shales	4,000
Marine shales and limestones	500
Upper sandstone	200
Upper coal seam	2-4
Middle sandstone	180
Lower coal seam	5-6
Lower sandstone	210

(After Krishnan, 1949.)

DESCRIPTION

The fossil is well preserved and represents the splenial dentition of a Ganoid Pycnodont fish. The arrangement of the teeth

is in a very definite pattern of two series of nearly equal, almost rounded teeth and another represented by a single transversely elongated, smooth, oval tooth with an adjoining impression of another member of this series. In the arrangement of the teeth our specimen agrees closely with that of the splenial dentition in the genus *Coelodus* Heckel, and the species which shows the closest resemblance is *Coelodus fimbriatus* described and figured by Woodward (1909A) where the general arrangement of the splenial dentition and the shape of the teeth are somewhat similar but differ in the detailed form and size of the teeth. In *Coelodus fimbriatus* reproduced here (Pl. 22, Fig. 5), the teeth in the principal series are slightly concave posteriorly and are about three times as broad as long, whereas in the specimen under report the single tooth representing the principal series is quite oval and is only about twice as broad as long. In these respects, the specimen under report differs from any of the species of *Coelodus* so far described. We are, therefore, inclined to consider this specimen as a new species of *Coelodus* and designate it *Coelodus jacobi* after Dr. K. Jacob, Palæontologist, Geological Survey of India, in recognition of the help received from him in the study of the fossil.

Coelodus jacobi sp. nov.

(Pl. 22, Figs. 1-4)

The splenial dentition is represented by a single transversely elongated, smooth, oval tooth of the principal series and two rows of almost rounded teeth of the flanking series (Figs. 1, 2). The outer row of the flanking series has three teeth, while the inner has four all nearly similar in size, slightly broader than long with a smooth or feebly rugose upper surface having a shallow coronal pit (Fig. 4). The tooth of the principal series is twice as broad as long with a slightly convex upper surface (Fig. 3). The width of the outer series together exceed that of the tooth of the principal series. They are all of a shining black colour with a short base firmly anchylosed to the supporting matrix.

The splenial dentition comprising three series of teeth (those in the innermost row being large and transversely elongated), is characteristic of the genus *Coelodus* and is not met with in other Pycnodonts.

Coelodus, according to Zittel (1932), is known from "Lower Cretaceous of Istria, Dalmatia, Southern Italy and England; also Cenomanian and Turonian in Europe and North America, and the family Pycnodontidæ from Lower Lias to Upper Eocene". Considering its stratigraphic position and the associated fossils the specimen described here is most probably Middle Eocene in age.

The fossil (G. S. I. Type No. 17473), is preserved in the collections of the Geological Survey of India.

PALAEOGEOGRAPHICAL REMARKS

Pycnodus lametæ Woodward (1909) from the Cretaceous fresh water deposits of Dongargaon in Madhya Pradesh is the only Pycnodont fish so far known from India. The occurrence of a Pycnodont fossil teeth in the marine deposits of the Garo Hills, Assam, is therefore, of some palæogeographical interest. Hora and Menon (1952) pointed out that during the Mesozoic there existed a land bridge across the ancient extension of the Tethys Sea in the Assam region connecting Peninsular India and the northern land mass. From a study of the past distribution of fresh-water fishes in India, it was then pointed out that this land bridge had probably persisted up to the Eocene when the transgression of the Bay of Bengal submerged it. The present discovery of the fossil Pycnodont teeth from the probable Middle Eocene deposits of Assam makes it possible to fix with some reservation, the period of the major transgression of the Bay of Bengal and the final submergence of the land bridge probably as the Middle Eocene. The marine gap created then possibly continued to exist till the Pliocene when brackish water, marshy conditions had set in, which enabled the migration of marsh-loving fishes from the east to India (Menon, 1951).

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We are grateful to Dr. M. S. Krishnan, Director, Geological Survey of India for giving us the opportunity of examining this interesting specimen and to Dr. S. L. Hora, Director, Zoological Survey of India for his useful suggestions.

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ZITTEL, K. A. VON. (1932).—Text-Book of Palaeontology. *London*.

EXPLANATION OF PLATE

PL. 22. FIG. 1. *Coelodus jacobi*, sp. nov. Part of palate showing splenial dentition. G. S. I. Type No. 17473.

FIG. 2. *Coelodus jacobi*, sp. nov. View partly from the side.

FIG. 3. *Coelodus jacobi*, sp. nov. Single median tooth enlarged × 2.

FIG. 4. Coelodus jacobi, sp. nov. Single lateral tooth enlarged × 2.

FIG. 5. *Coelodus fimbriatus* Woodward. Right splenial dentition (After A. S. Woodward, 1909A).

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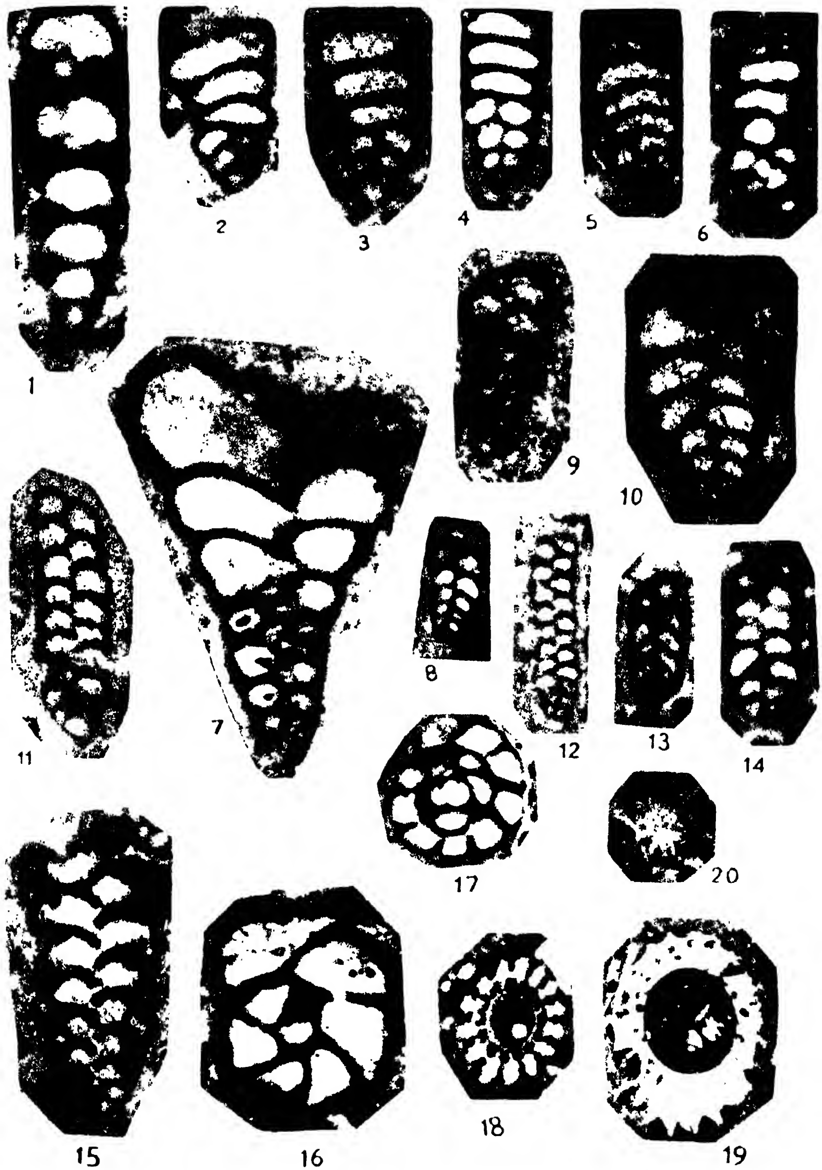


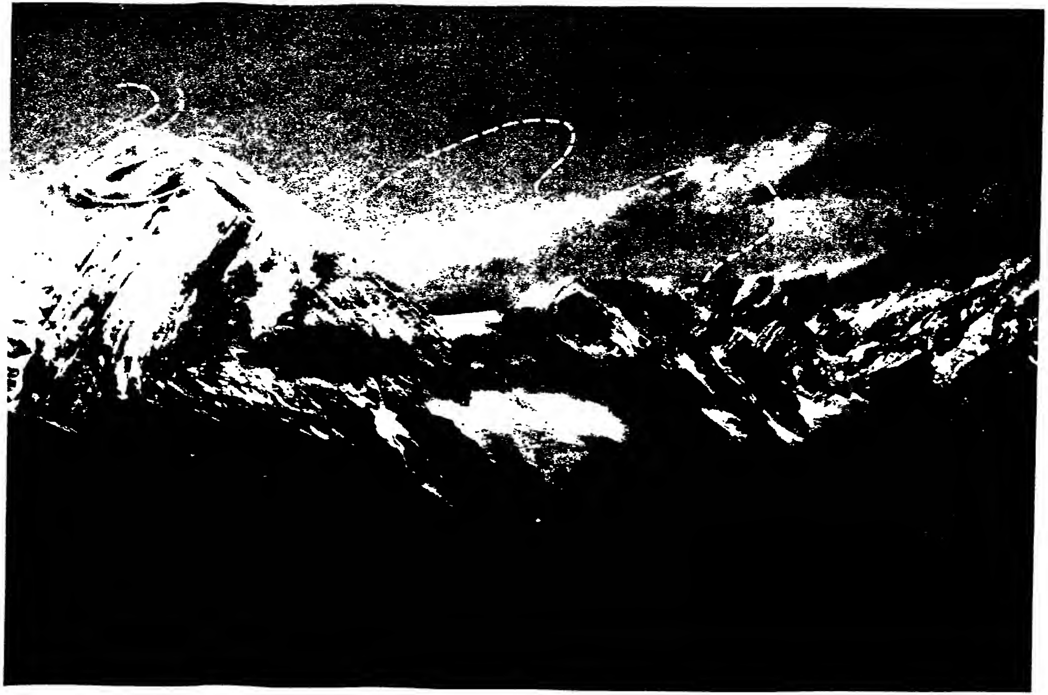
MICROFORAMINIFERA FROM THE ORBITOLINA BEARING ROCKS OF TIBET AND BURMA

Photo, M. R. Sahni & V. V. Sastri.

G. S. I., Calcutta

Composite photograph of Dhaulagiri (26,795 ft.) and environs showing probable geological structure and hanging glacier. View from height of about 14,000 ft., above Kali Gandaki valley, facing approximately north-west.

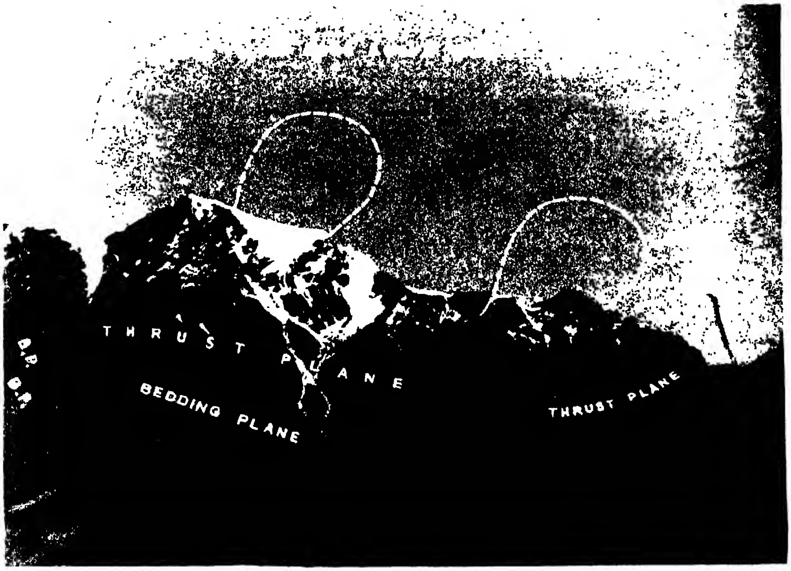
Photo, M. R. Sahni. *G. S. I., Calcutta.*



Dhaulagiri and its continuation. View from height of about 14,000 ft., facing approximately W.N.W. A sharp synclinal fold forms the crest of the main peak. For structure of the northern end of the range see Plate VI.

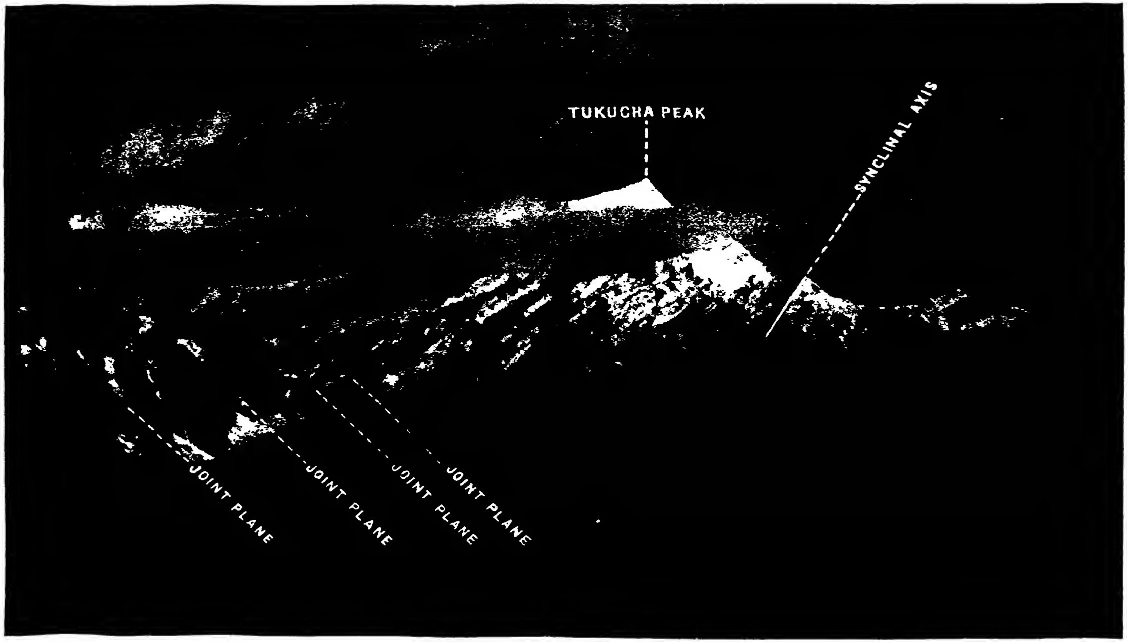
Photo, M. R. Sahni.

G. S. I. Calcutta



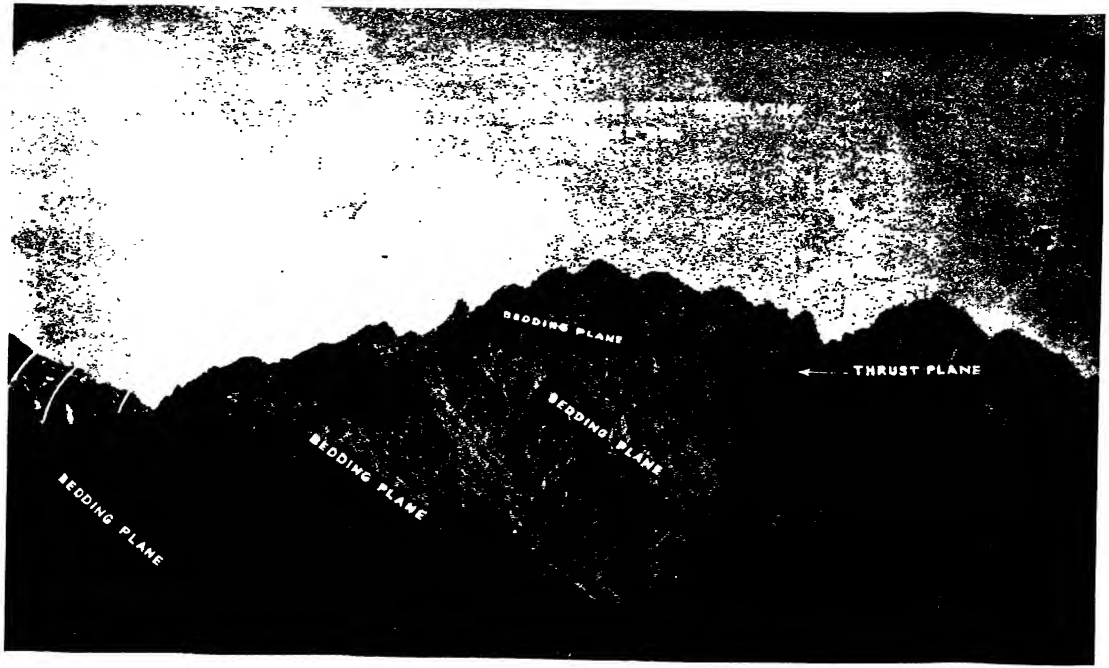
Highly folded zone north-east of Dhaulagiri thrust over bedded sequence dipping at an angle of about E30°N. Thrustplane indicated by a prominent line. This is interpreted as the main overthrust of fossiliferous rocks of the Tibetan zone. View from about 17,000 ft., facing approximately north west.

Dhaulagiri with hanging glacier; outline of peak reflected in the clouds below. View taken on return journey, facing approxi-

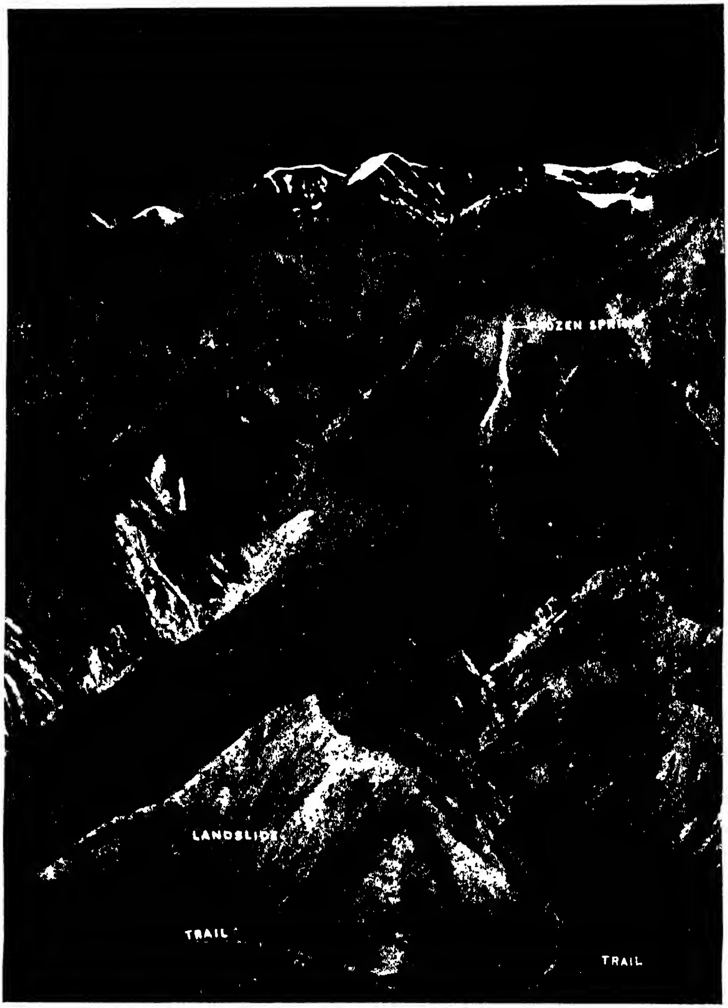


Hill range north-east of Dhaulagiri with the prominent Tukucha peak. Note synclinal structure and at least four well defined joint planes. View from height of about 13,000 ft., above kali Gandaki valley; facing approximately W. N. W.

Photo. M. R. Sahni. *G. S. I., Calcutta.*



Northward extension of hill range shown in Pl. V, fig. 1. The thrustplane seen in Pl. V, fig. 1, is continued here as an almost horizontal line truncating a bedded sequence dipping N.E. at 45°, approximately. View from height of about 12,000 ft., facing north-west. This is probably a local thrust. High dipping strata seen in hill range in back-ground, extreme left.



Trail to Muktinath, Mustang, etc., running across an extensive landslide (bottom.) Frozen spring below cirque with semicircular margin.

Photo. M. R. Sahni. *G. S. I., Calcutta.*

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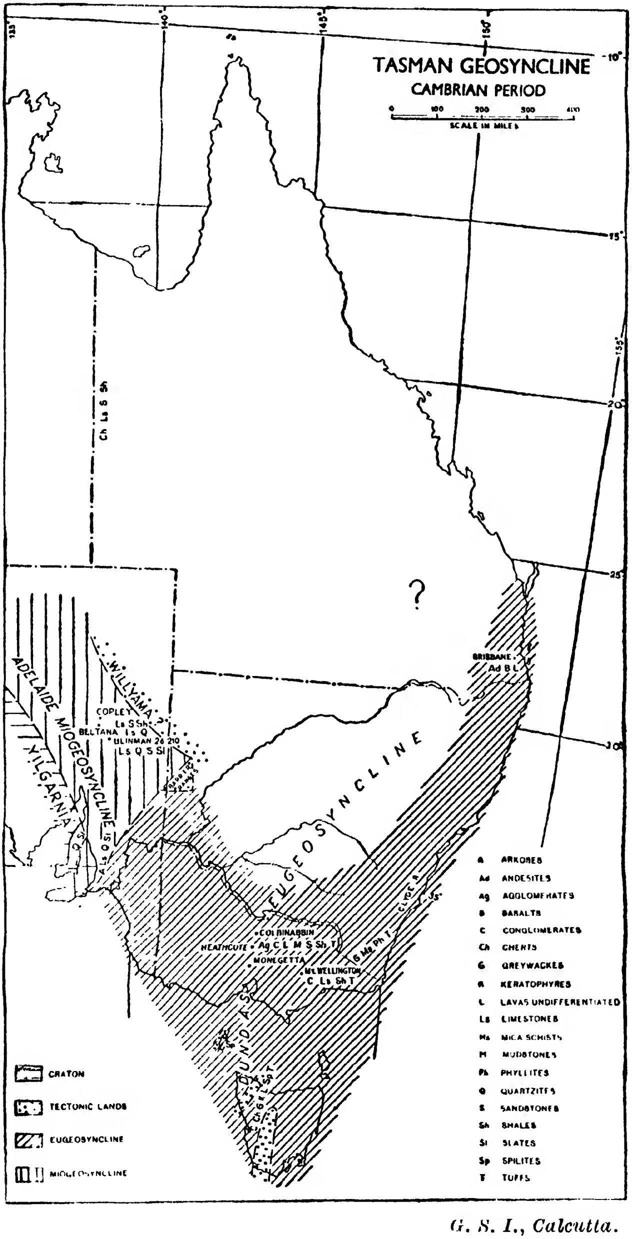

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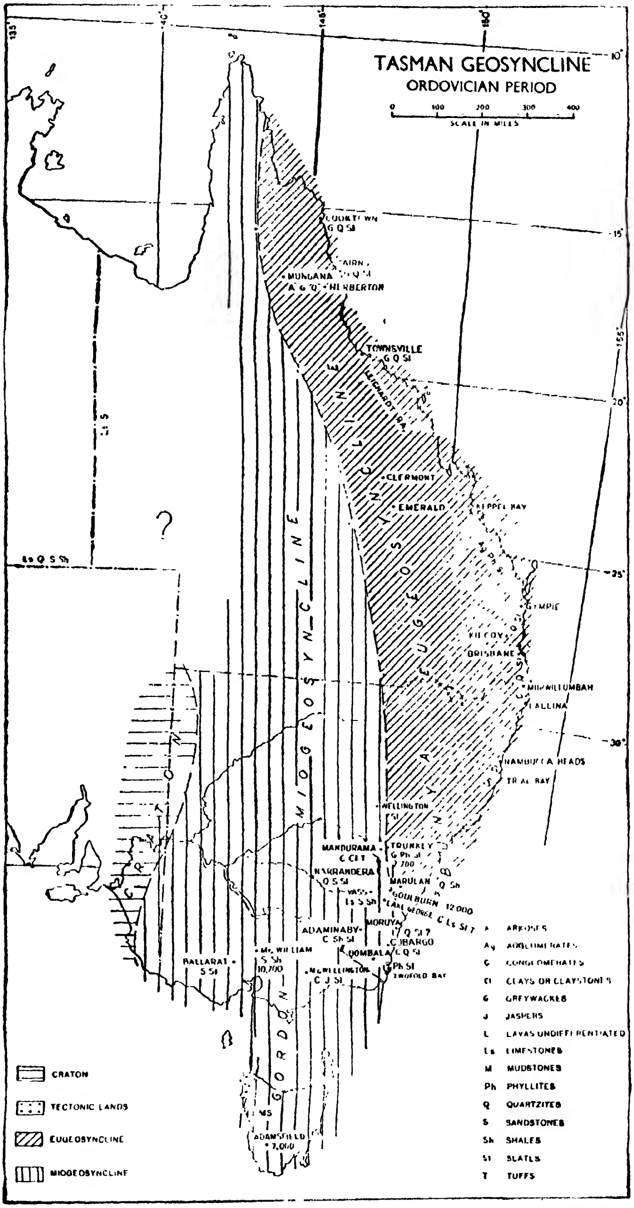
TASMAN GEOSYNCLINE
ORDOVICIAN PERIOD
SCALE IN MILES
0 100 200 300 400
COOKTOWN G Q Sl
MUNGANA
HERBERTON
TOWNSVILLE G Q Sl
LEICHARDT RA.
CLERMONT
EMERALD
KEPPEL BAY
GYMPIE
KILCOY
BRISBANE
MURWILLUMBAH
BALLINA
NAMBUCCA HEADS
WELLINGTON
MANDURAMA C Cl T
TRUNKEY G Ph Sl 700
NARRANDERA Q S Sl
YASS Ls S Sh
MARULAN Q Sh
GOULBURN 12,000
LAKE GEORGE C Ls Sl ?
MORUYA
COBARGO
ADAMINABY C Sh Sl
BOMBALA C Q Sl
Ph Sl
TWOFOLD BAY
BALLARAT S Sl
Mt. WILLIAM S Sh 10,700
Mt. WELLINGTON C J Sl
ADAMSFIELD 7,000
Ls Q S Sh
?
MIOGEOSYNCLINE
EUGEOSYNCLINE
GORDON
CRATON
TECTONIC LANDS
EUGEOSYNCLINE
MIOGEOSYNCLINE
A ARKOSES
Ag AGGLOMERATES
C CONGLOMERATES
Cl CLAYS OR CLAYSTONES
G GREYWACKES
J JASPERS
L LAVAS UNDIFFERENTIATED
Ls LIMESTONES
M MUDSTONES
Ph PHYLLITES
Q QUARTZITES
S SANDSTONES
Sh SHALES
Sl SLATES
T TUFFS
135
140°
145°
150°
155°
10°
15°
20°
25°
30°

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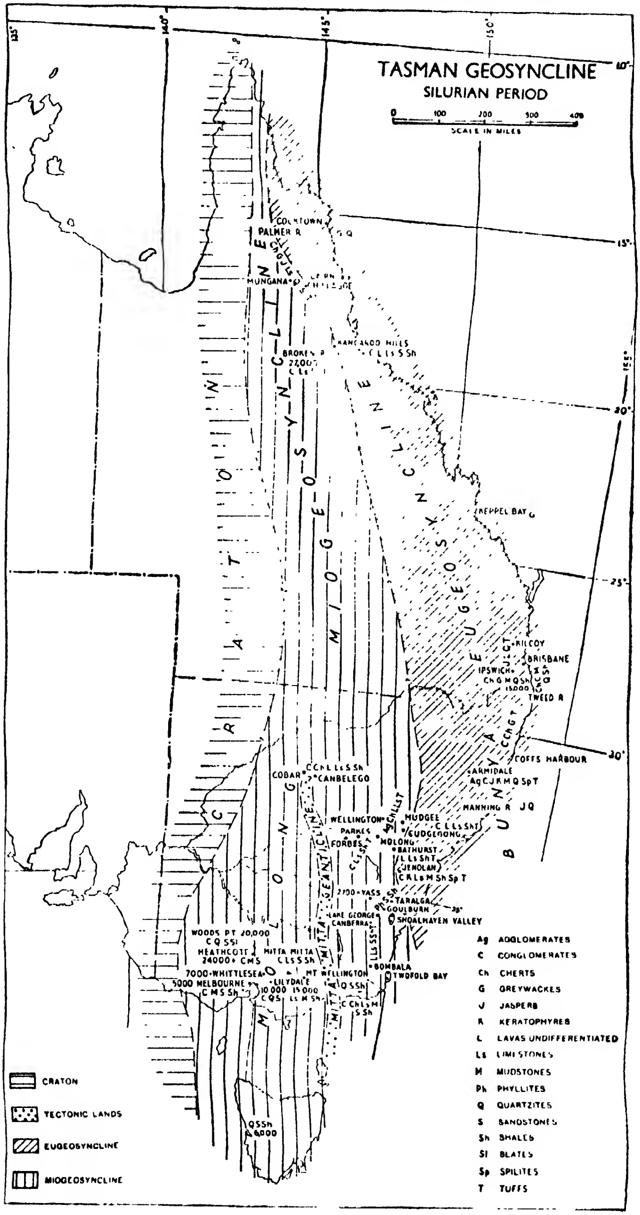

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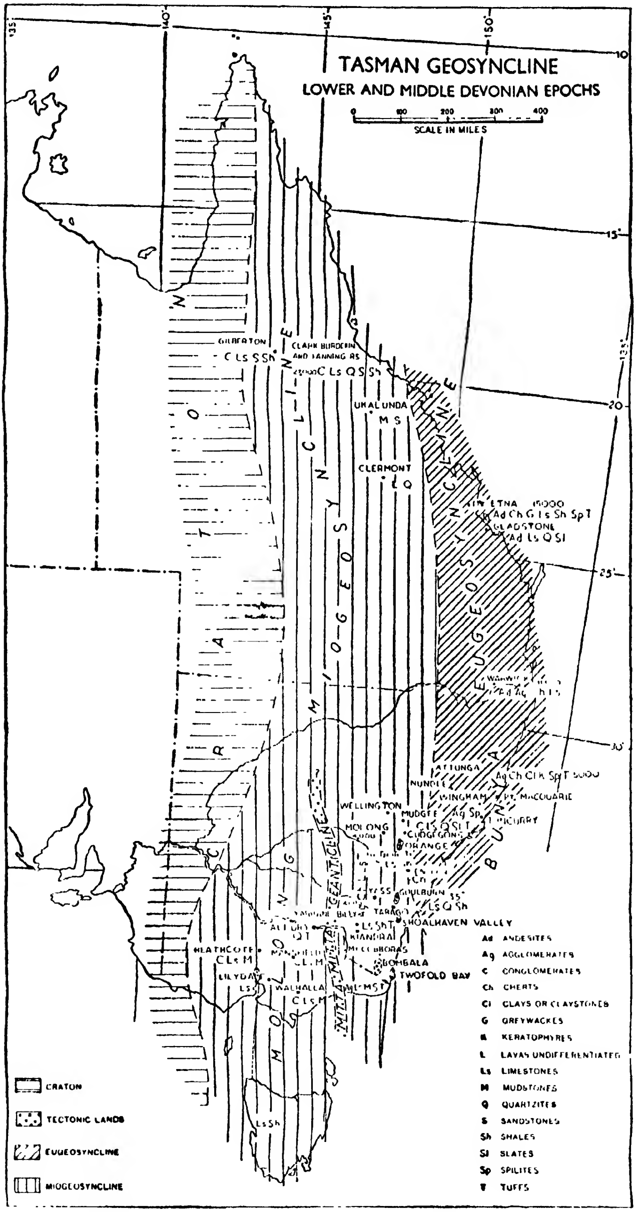
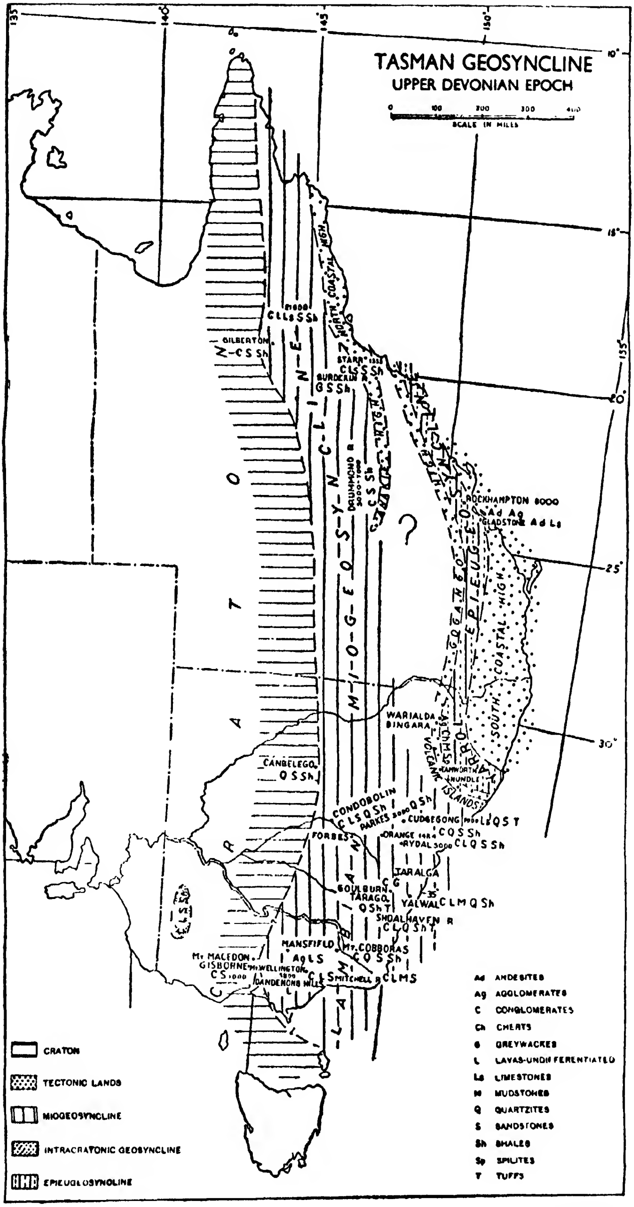
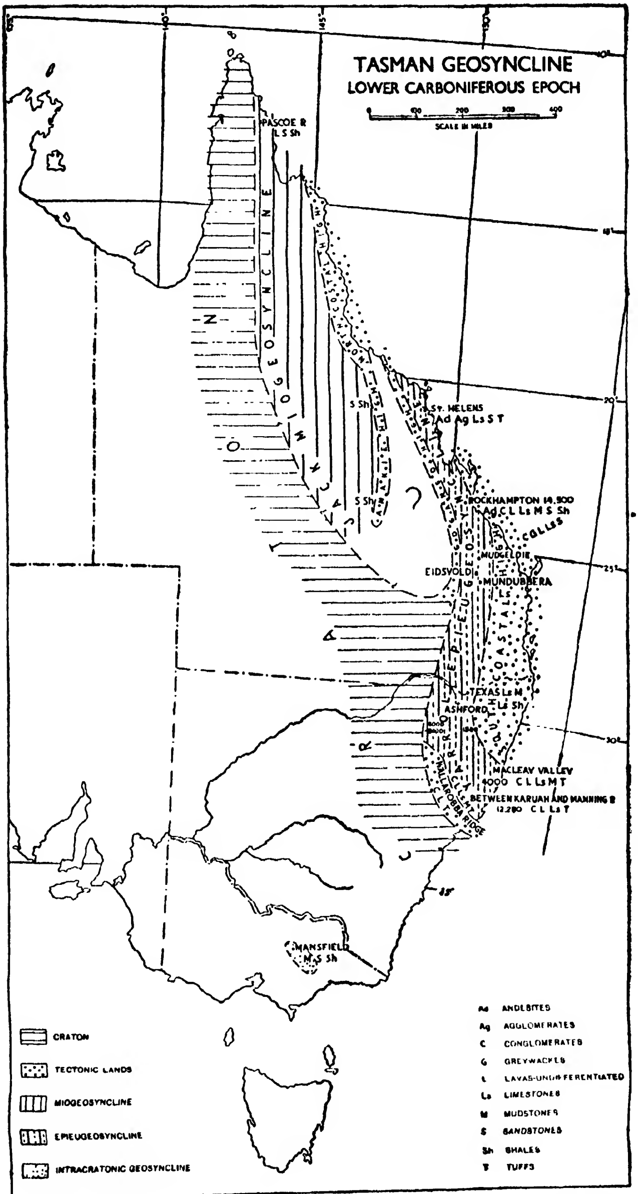



TASMAN GEOSYNCLINE
UPPER DEVONIAN EPOCH
SCALE IN MILES
CRATON
TECTONIC LANDS
MIOGEOSYNCLINE
INTRACRATONIC GEOSYNCLINE
EPIEUGEOSYNCLINE
Ad ANDESITES
Ag AGGLOMERATES
C CONGLOMERATES
Ch CHERTS
G GREYWACKES
L LAVAS-UNDIFFERENTIATED
Ls LIMESTONES
M MUDSTONES
Q QUARTZITES
S SANDSTONES
Sh SHALES
Sp SPILITES
T TUFFS
ROCKHAMPTON
GLADSTONE
WARIALDA
BINGARA
CANBELEGO
CONDOBOLIN
PARKES
CUDGEGONG
ORANGE
RYDAL
FORBES
TARALGA
GOULBURN
TARAGO
YALWAL
SHOALHAVEN R
MANSFIELD
MT. COBBORAS
MT. MACEDON
GISBORNE
MT. WELLINGTON
DANDENONG HILLS
MITCHELL R
GILBERTON
BURDEKIN R.
DRUMMOND R
NORTH COASTAL HIGH
SOUTH COASTAL HIGH
TAMWORTH
NUNDLE


TASMAN GEOSYNCLINE
LOWER CARBONIFEROUS EPOCH
SCALE IN MILES
PASCOE R
L S Sh
ST. HELENS
Ad Ag Ls S T
ROCKHAMPTON 14,500
Ad C L Ls M S Sh
MUDGELDIE
EIDSVOLD
MUNDUBBERA
TEXAS Ls M
ASHFORD
Ls Sh
MACLEAY VALLEY
4000 C L Ls M T
BETWEEN KARUAH AND MANNING R
12,200 C L Ls T
MANSFIELD
M S Sh
CRATON
TECTONIC LANDS
MIOGEOSYNCLINE
EPIEUGEOSYNCLINE
INTRACRATONIC GEOSYNCLINE
Ad ANDESITES
Ag AGGLOMERATES
C CONGLOMERATES
G GREYWACKES
L LAVAS-UNDIFFERENTIATED
Ls LIMESTONES
M MUDSTONES
S SANDSTONES
Sh SHALES
T TUFFS

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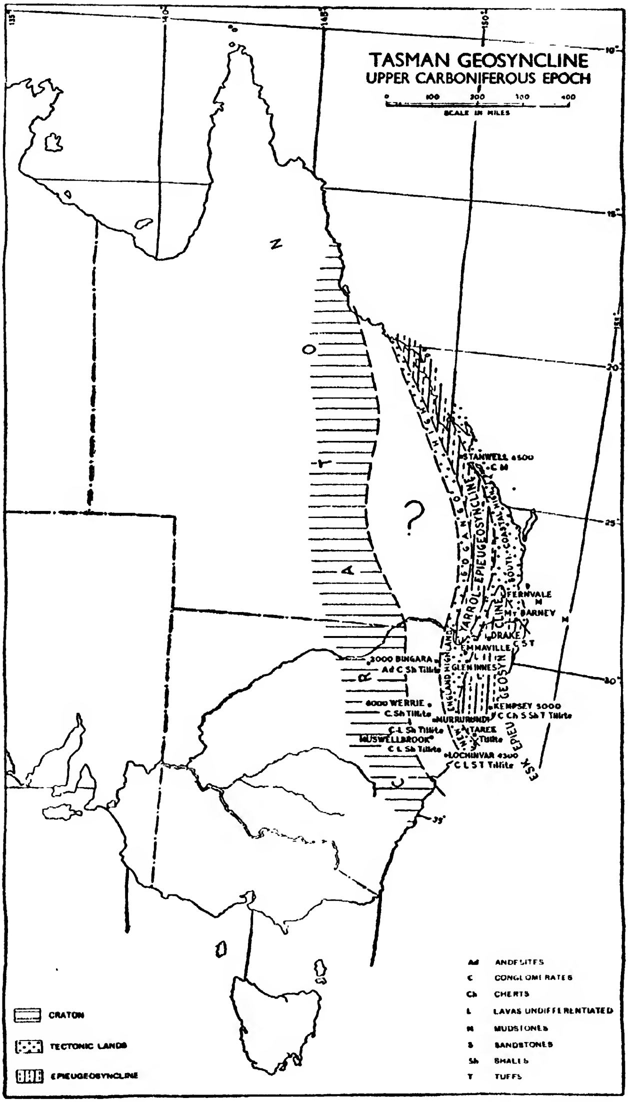

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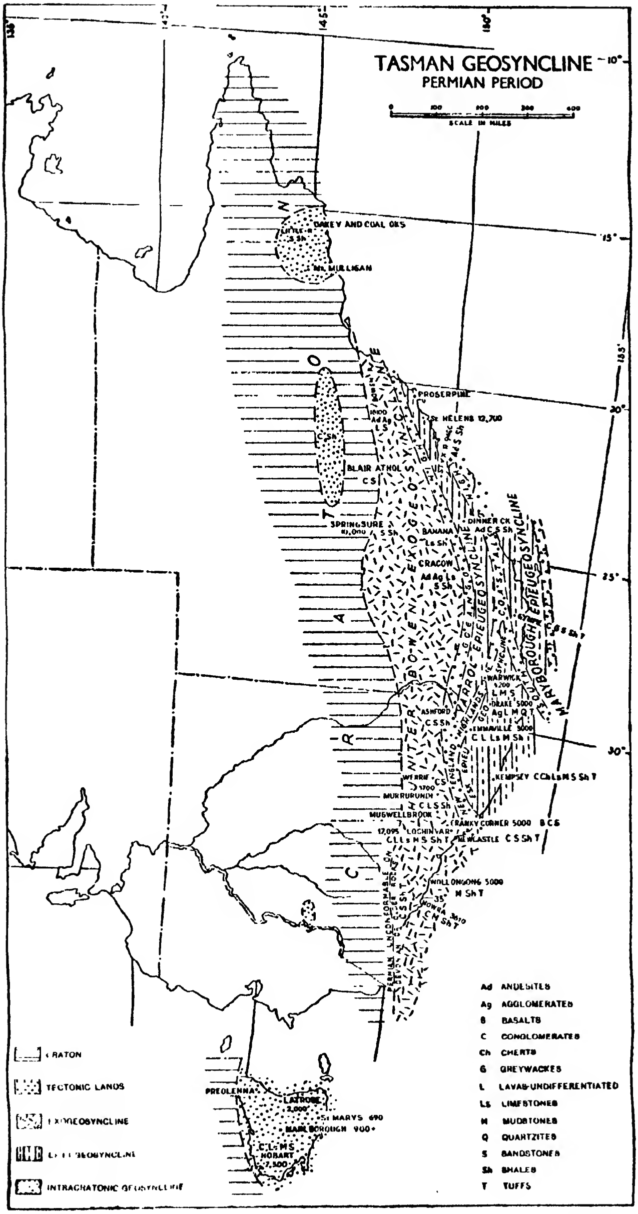
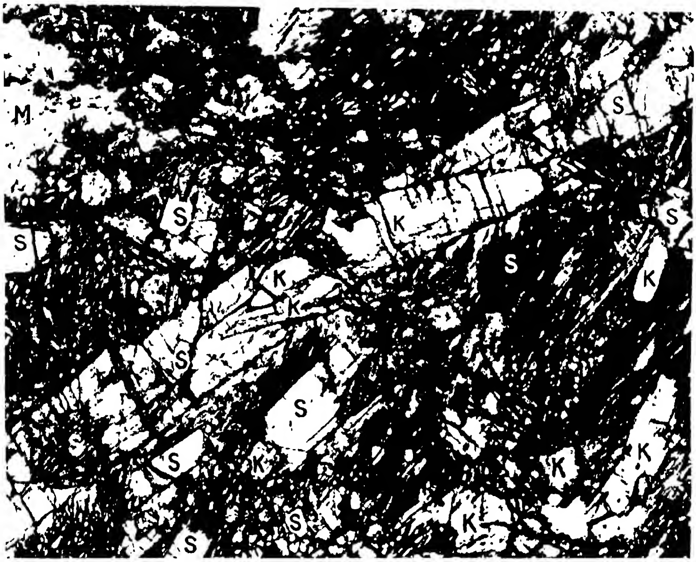

TASMAN GEOSYNCLINE
PERMIAN PERIOD
SCALE IN MILES
PROSERPINE
St HELENS 12,700
BLAIR ATHOL
SPRINGSURE
BANANA
CRACOW
DINNER CK
WARWICK
DRAKE 5000
EMMAVILLE 5000
ASHFORD
KEMPSEY
MURRURUNDI
MUSWELLBROOK
LOCHINVAR
NEWCASTLE C S Sh T
WOLLONGONG 5000
PREOLENNA
LATROBE
MARLBOROUGH 900+
HOBART
Ad ANDESITES
Ag AGGLOMERATES
B BASALTS
C CONGLOMERATES
Ch CHERTS
G GREYWACKES
L LAVAS-UNDIFFERENTIATED
Ls LIMESTONES
M MUDSTONES
Q QUARTZITES
S SANDSTONES
Sh SHALES
T TUFFS
CRATON
TECTONIC LANDS
INTRACRATONIC GEOSYNCLINE



Kyanite (K) associated with Sillimanite (S). The plate essentially consists of sillimanite needles of varying size, with some grains of Kyanite showing the typical cleavages. (M) Muscovite and sericite. Ordinary light.

Photo, M. V. N. Murthy & S. C. Saha. *G. S. I., Calcutta.*

Fig. 1. Fragmentary Vindhyan quartzite in the breccia at the base of the boulder bed, west of Bekha.

Fig. 2. A specimen of breccia showing the *angular nature of the fragments.*

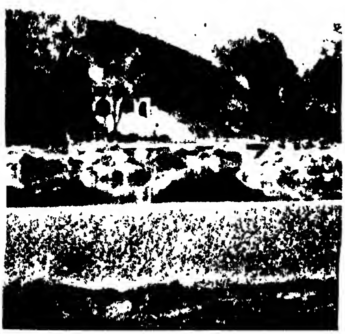


Fig. 3. Cave temple of Jayanti Mata in the breccia, with on inlier of dolomite in the foreground.

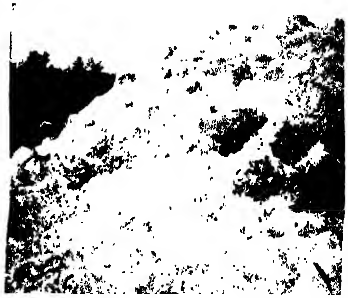


Fig. 4. Boulders of the Vindhyan quartzite in the breccia, Choral river section, south of the road to Sortipura.

Photos, M. K. Roy Chowdhury

G. S. I., Calcutta.

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Fig. 1.

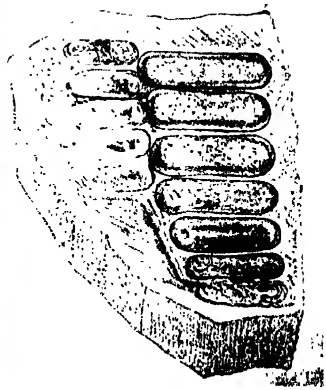

Fig. 3.

Fig. 2. (x 3)

COELODUS PARALLELUS (DIXON) VAR. FEDDENI NOV.

Photos. K. N. Prasad & V. Raghavendra Rao. G. S. I., Calcutta.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 5.

Fig. 4.

Photo, A. G. K. Menon & K. N. Prasad.

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